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MINUTES AND PROCEEDINGS

of the Twenty-eighth meeting of the

ARMED FORCES - NRC VISION COMMITTEE

April 6-7, 1951

The National Academy of Sciences
Washington, D. C.

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Minutes of the Twenty-eighth meeting

April 6-7, 1951

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Friday, April 6 Page

1. The chairman asked for corrections or additions to the Minutes and Proceedings of the 27th meeting.

   Dr. Gertrude Rand suggested that item 5 on page 42 may be confusing as it reads in that there are two Hardy, Rand, Rittler selections of pseudo-isochromatic plates. In order to make it perfectly clear to which set the comment refers, item 5 might better be written as follows:

   > 5. The commercially-available Hardy, Rand, Rittler selection of 18 plates uses 11 plates which are also included in the proposed test. Since it has 7 plates which are not in the 14-plate test, and the latter has 3 plates not in the Hardy, Rand, Rittler selection, the two tests are sufficiently different to prevent malingering.

2. Dr. Benjamin J. Wolpaw presented a summary report of the status of the Armed Forces Visual Screening Examination, a summary of which is contained in the Proceedings 20

3. Dr. Louise L. Sloan presented a report entitled "Comparative studies of visual acuity with different test objects," a text of which is contained in the Proceedings 21

4. Dr. Forrest L. Dimmick presented a paper entitled "Visual acuity requirements for submarine enlisted personnel," the text of which is contained in the Proceedings 28

5. Captain Thomas L. Willmon presented a brief discussion of the operational significance of visual requirements for submarine personnel, a text of which is contained in the Proceedings. 34

6. Dr. H. W. Rose represented a paper entitled "A Portable Motion Parallax Tester," a summary of which is contained in the Proceedings 37

7. Dr. Richard G. Scobee presented a paper entitled "Evaluation and treatment of hyperphoria," the text of which is contained in the Proceedings . . . .

8. Dr. Edward S. Lamar presented a paper entitled "Visual detectio in air interception," a text of which is contained in the Proceedings* 43

9. Dr. E. O. Hulburt presented a paper entitled "Brightness of the twilight sky," a text of which is contained in the Proceedings 54

*This report is classified CONFIDENTIAL and will be found only in those copies of the Minutes which are classified CONFIDENTIAL.

14. Members of the Vision Committee traveled to Fort Belvoir, Virginia, to witness a demonstration of the use of artificial moonlight to increase visibility in night operations. Admirable arrangements were made by personnel of the Engineer Research and Development Laboratories at Fort Belvoir to demonstrate the searchlight techniques. Foot soldiers and a tank maneuvered in the neighborhood of the Vision Committee members along predetermined attack courses, and the members of the Committee were able to see at first hand the effects upon visibility produced by the addition of searchlight illumination.

Saturday, April 7

Report on the Present Status of the Armed Forces Visual Screening Examination

Benjamin J. Wolpaw

The Armed Forces Visual Screening Examination, which has been developed by a working group of the Vision Committee, represents the culmination of a five-year program of discussion and development. The suggestion that a machine-type test be utilized in the Military Departments for the testing of visual functions was suggested by members of the Vision Committee in 1946. Such a test has the advantage that it eliminates the bad testing conditions which arise from employing visual alleys and that it provides carefully standardized conditions for different military test stations. The inadequacies of test conditions which were evidenced during the last war still may be found in military stations engaged in testing vision. Therefore, the need for a machine-type test is no less real now than it was during the last war.

Members of the Vision Committee have been informed of the status of the Armed Forces Visual Screening Examination at various times during the period devoted to its development. It is now possible to report that the Examination is entirely completed, and that the recommendation of the Vision Committee will soon be forwarded to the Surgeons General for their consideration.

The form of the Armed Forces Visual Screening Examination is described in full in a Manual which will soon be published by the Vision Committee Secretariat and made available to the members of the Committee. The Vision Committee has already approved the recommendation that the Screening Examination be adopted by the Military Departments, and it is anticipated that such adoption will be forthcoming.

All the members of the working group have contributed to the development of the examination. Special mention, however, should be made of the significant contribution made by Dr. Louise Sloan who not only tested a number of the slides, but who personally wrote the Manual which describes the test and which will be used for indoctrination of technicians who will administer the examination.

A Comparison of Different Test Objects and Procedures for Measuring Visual Acuity

Louise L. Sloan, Wm. M. Rowland and Adelaide Altman

Studies we have been making for the past few years under an ONR contract include as one of their objectives the development of a simple and reliable method of measuring visual acuity suitable for use by the Armed Forces.

There is an extensive literature concerned with the testing of visual acuity, which provides definite answers to certain aspects of the problem. It can, for example, be concluded from the data of previous studies (1) that if the contrast between dark test object and light background is at least 85%, and if the brightness of the background is maintained constant between limits of about 12 to 18 ml., variations in contrast and brightness within these limits will not produce changes in acuity of any practical significance. Some information related to the question of the most suitable gradation of sizes on an acuity chart is also provided by previous studies. Fig. 1 shows data derived from the studies of Crawford, Shagass and Pashby (2) and Kempf Collins and Jarman (3). Crawford's data are for 289 eyes with simple myopia; Kempf's data are for 1148 eyes with simple hyperopia tested under cycloplegia. This graph shows the average diopters of spherical refractive error associated with each level of visual acuity. The equation of the straight line is $A = 2.8\ S$ where A is the threshold visual angle in minutes, S is diopters of spherical error. From this equation it can be concluded that if the letter sizes are, in Snellen notation, 20/20, 20/30, 20/40, 20/50, 20/60, etc., i.e., if they increase by steps of 1/2 minute of visual angle, then each increase in spherical refractive error of about 0.2 diopter will reduce acuity by one line on the chart. The data of these two studies are not adequate to determine whether the same relationship holds for acuities poorer than 20/100. The equation obviously cannot be applied to acuities better than 20/20. In this range the effect of refractive error is negligible, and acuity is limited by the resolving power of the retina itself. Crawford's data for eyes with simple and with compound myopic astigmatism, when treated in the same way, suggest that the relationship may again be linear and that the equation $A = 2.8\ (S + 0.8C)$ gives a close approximation to the data. In this equation S is the spherical error in diopters, C the cylindrical error, and A is the threshold visual angle. Further studies of this type are needed to confirm these relationships, and some other type of investigation is needed to determine the most suitable gradation of letter sizes smaller than 20/20. However, between the limits of 20/20 and 20/100 (i.e., 1 minute and 5 minutes in visual angle notation), the results suggest that the sizes of test object should vary by equal steps on a visual angle scale, not on an acuity scale or a logarithmic scale. Acuity charts in general use at the present time are not graded consistently in terms of any unit.

Next I should like to discuss our own data which were obtained in an attempt to answer two specific questions not adequately solved by previous studies. The first question pertains to the selection of test object, the second concerns the validity of acuity tests in which distance is simulated optically as it is, for example, in the Ortho-Rater, Sight-Screener and Telebinocular.

Three types of test object were compared, namely the Ortho-Rater checkerboard, the Landolt ring and the group of 10 letters which you have been shown in numerous previous meetings. In this comparison all 3 tests were given by means of slides viewed in the Ortho-Rater.

The standard checkerboard slide has 15 different sizes varying by equal steps on an acuity scale, where acuity is defined as the reciprocal of the visual angle in minutes. In order to make the 3 tests comparable, exactly the same series of visual angles was used for the letter and Landolt ring slides. Figure 2. In this slide the standard checkerboard test for the right eye is shown at the top. The letter slide for the left and right eyes is shown at the bottom. You will notice that the letter slide has 10 items of each size

except the largest. There was room for only five letters of the 20/200 size. The Landolt ring slide has the same number of items at each level as the letter slide and is composed of rings with openings at the top, bottom, right and left.

The checkerboard test, as given in this study, differed in 3 respects from the standard test. FIRST. The acuity of each eye was tested with occlusion of the other eye in order to keep the experimental conditions the same as those used for the tests with letters and rings. SECOND. In the standard Ortho-Rater the brightness of the white portions of the checkerboard slide is about 150 ml. We used a brightness of 33 ml. for the first 136 eyes tested, 15 ml. for the remaining 82 eyes. (Although the brightness level was changed in the middle of the study, for any one subject it was the same for all 3 test objects.) THIRD. Since on the checkerboard slide there is only one item of each size, two separate determinations of acuity were made and the scores averaged. Each individual score was the last item read correctly before the first error was made. In some previous studies, Cook's at New London, for example, the score used was the last item read correctly before 2 successive errors. Our preliminary studies indicated that because one in four responses can be correctly given by chance, Cook's method overestimates the acuity of many subjects. The standard method of scoring the Ortho-Rater acuity test is perhaps slightly different from that used by Cook. Its description in the Ortho-Rater manual is somewhat equivocal. Jane Davis of Bausch & Lomb has written me a fuller explanation which I have with me and will be glad to read if anyone asks for it and if I can have an additional 5 minutes. The scoring method we used seemed to us to be the most logical, and I am glad to learn from Dr. Dimmick that after an extensive statistical study, he has found our method to agree most closely with scores based on 10 items at each level. The acuity score on the letter and ring tests was the smallest size at which 7 or more of the 10 characters were identified correctly. (On the top line having only 5 characters the passing score was 3 or more correct.) If we had chosen the 50% level instead of the 70% level, there would have been no change in the scores of a majority of the subjects, because the average subject reads only 3 or 4 items correctly on the line just below the lowest line on which 7 or more are read correctly.

Selection of Subjects:

In obtaining suitable subjects for a comparison of the 3 types of test target, we kept in mind the primary purpose for which tests of visual acuity are used in the military services. Present regulations do not require the discrimination of individual differences among those who have acuities of 20/20 or better. We therefore chose our subjects so that about 3/4 would have acuities between 20/20 and 20/200 and only about 1/4 would have acuities better than 20/20. Only those free of ocular disease and between the ages of 14 and 40 were studied. Those with acuities less than 20/200 were not included. No other selection of subjects was made. They differ from a random population therefore only in that they include a smaller proportion with acuities better than 20/20.

Results:

Figure 3 shows for 218 eyes the average ring acuity for each of 8 ranges of letter acuity. This is therefore an observed regression line. The calculated regression equation for predicting ring acuity from letter acuity is $Y' = 1.04X - 0.07$ where Y' and X are expressed in units of decimal acuity.

The mean decimal acuity is 0.80 for letters, 0.77 for rings. In Snellen notation the mean acuities are 20/25 and 20/26, or $\frac{16}{20}$ and $\frac{15.4}{20}$ if the Grow system is used. The standard deviations for letters and rings respectively are 0.39 and 0.45. The correlation between the two sets of measures is 0.90. Unfortunately we cannot compare the correlation coefficient with the test-retest coefficients of the same group because no retests were made. Data from the AGO study, however, give test-retest coefficients of 0.85 and 0.87 for New London and AAF letters.

Although the differences in the means and in the standard deviations are statistically significant, they are probably not of practical significance. If, for example, this particular letter test were accepted as the standard test for literate subjects, the Landolt ring is so nearly equivalent that it could be accepted as an adequate substitute for testing illiterates.

Figure 4 shows for 219 eyes the relationship between letter and checkerboard acuity. The circles are the average checkerboard acuities for each of 8 ranges of letter acuity. We have not made any further statistical analysis of these data, but it is apparent that there is not a linear relationship between the two variables. We have made the same sort of graph of Cook's data for New London letters and checkerboard targets, and of Imus' data for Grow letters and checkerboard targets. These data differ quantitatively from ours, probably because of differences in the method of scoring the checkerboard test, and differences in the brightness of the background. They agree, however, in showing a curvilinear relationship between the two variables.

A determination of visual acuity using the checkerboard target can undoubtedly be made more quickly than with letter or ring targets. This is because fewer items are required at each level to give the same reproducibility. If, however, it is accepted that ability to recognize complex shapes such as letters provides a valid measure of acuity, then it is obvious that the checkerboard target overestimates acuities below about 20/30 and underestimates them at higher levels.

We have a tentative explanation to suggest for the overestimation of acuity by the checkerboard targets at levels of below 20/30. Figure 5 shows the effect on acuity of spherical and astigmatic errors of refraction produced artificially, for letter, ring and checkerboard test objects. With spherical errors of refraction the reduction in acuity with increase in refractive error is not markedly different for the 3 types of test object. Astigmatic errors at oblique axes, as would be expected, produce somewhat less impairment of acuity than spherical errors of the same magnitude. In both cases the reduction in acuity with increase in error of refraction is perhaps slightly less for the checkerboard target. The third graph shows the effect on acuity of astigmatic errors in the vertical and horizontal meridians. For letters and Landolt rings the effects are about the same as for astigmatic errors at oblique axis. With the checkerboard, however, there is practically no decrease in acuity with astigmatic errors as high as 2 diopters.

If we look again at Figure 2, I think you can see why this happens. Blurring of the checkerboard target in either the vertical or the horizontal meridian only, will cause it to appear more or less as a series of dark and light bars instead of as a checkerboard. If, however, the subject can still distinguish the checkerboard square from the confusion squares, his apparent acuity will show little or no impairment. We recognize that a temporary error of refraction produced artificially by lenses probably reduces acuity more than the same refractive error, which has been present long enough for the subject to learn to interpret the blurred images. We hope some day to have enough data to provide independent determinations of the relationship between checkerboard and letter acuity for two groups of subjects (a) those with uncorrected simple astigmatisms at 90^o and 180^o and (b) those with spherical errors and astigmatisms at oblique axes. Such data may or may not provide an explanation for the differences in acuity as measured by letters and Landolt rings, and as measured by checkerboard targets. Whatever the explanation may be, the fact remains that measures of acuity obtained with checkerboard targets are far from equivalent to measures obtained with letters and Landolt rings. In the absence of any validating studies it seems to us that a test of ability to recognize familiar complex forms such as letters is probably more nearly related to the visual requirements of ordinary life than is ability to distinguish a checkerboard from a pattern of more finely-spaced dots. It is quite possible on the other

hand that the checkerboard test is an adequate screening test in industry, if the scores have been validated directly against performance on the particular job.

The next thing I should like to discuss is the reason we used single stroke letters without serifs and did not try to meet the rigid Snellen criterion that all component parts of letters of a given size should subtend the same visual angle. After reviewing the many attempts which failed to find Snellen type letters approximately equal in difficulty, even for subjects without refractive errors, and after studying the effects of different types of error on the appearance of such letters, we decided that perhaps Snellen's basic assumption was fallacious, and that the detail in a letter does not need to be completely resolved in order that the letter be recognized. The use of serifs, therefore, may merely complicate matters by making certain letters particularly difficult to recognize because of their unfamiliar form. Since the response is necessarily one of recognition, we decided to use everyday familiar letters, of as complex shape as possible so that blurring in any one meridian would make them unrecognizable. It was assumed that in any group of letters that might be chosen some would be relatively easy for one subject, and quite different ones easy for another. If, however, the same ten letters are used on each line, then each successively smaller line will be more difficult than the preceding one regardless of variations in difficulty among the individual letters.

The arguments for accepting this particular group of 10 letters as a measure of acuity are as follows:

(1) Since their form is familiar to all literate subjects, intelligence, training, etc., should not have an important effect on the scores.

(2) Because they are of complex form, recognition will be impaired by blurring of the image in any one meridian.

(3) Their average difficulty is in agreement with that recommended in 1930 by the Committee on Optics and Visual Physiology of the A.M.A. (4). This committee recommended that the letters used for measuring visual acuity be rated in difficulty by comparison with the Landolt ring.

(4) For the literate subject tests employing letters are unquestionably easier to give and to score than tests using the Landolt ring. Since this group of letters gives acuity ratings which differ only slightly from those obtained with Landolt rings, the latter may be used in the testing of illiterates.

The second question we have investigated is whether a test of acquity in which a distance of 20 feet or more is simulated by lenses is a valid substitute for a test at true distance. We have definite evidence that patients wearing hyperopic corrections for the first time occasionally find it easier to relax accommodation when viewing test objects at true than at simulated distance. A similar apparatus-accommodation may perhaps sometimes occur in other subjects.

Cook's extensive statistical comparison of acuity measures at true and at simulated distance were reported to the Visision Committee at New London in 1948. Cook found that with the Ortho-Rater type of target, acuity was slightly lower at true distance than at simulated distance whereas the reverse was true for the Sight-Screener. In these studies, as far as I can tell, there was no attempt to equate brightness and contrast for the two conditions, and the reproduction of the test targets at distance was faulty.

In our studies we used an identical letter chart in the Ortho-Rater and at a distance of 20 feet. The brightness of the background and the contrast between letter and background did not differ significantly for the two conditions. Seventy-eight subjects with acuities ranging from 20/200 to 20/13 were tested. The correlation between the two sets of measures is 0.92. The mean acuity in decimal notation is 0.84 at true distance, 0.77 at simulated

distance. In Snellen notation these means are 20/24 and 20/26, respectively, or on the Grow system $\frac{16.7}{20}$ and $\frac{15.4}{20}$. Thus the mean acuity is slightly higher at true distance. The standard deviations are 0.40 and 0.33 for true and simulated distance. The differences in the means and in the standard deviations are statistically significant. However, since the present acuity requirements are more or less arbitrary, and since testing conditions are not well standardized, there is no reason to suppose that substitution of the machine test for those now in use will make any important change in the standards. If investigations are ever undertaken to determine the levels of visual acuity actually required for certain military assignments, these findings can be related directly to scores on the new test.

Conclusions

(1) Apparatus-accommodation and other factors which might conceivably influence measures of acuity at simulated distance are not of practical importance.

(2) Visual acuity scores obtained with checkerboard test objects are not closely equivalent to those obtained with letters and with Landolt rings. One of the factors probably responsible for the difference is overestimation by the checkerboard target of the acuities of subjects with uncorrected astigmatic errors.

(3) The group of 10 non-serif letters used in this study are, in average difficulty, practically identical with Landolt rings having breaks in the vertical and horizontal positions. These two types of test character may therefore be used respectively for the testing of literate and nonliterate subjects.

References

1. a. Cobb, P. W. and Moss, F.K. The relation between extent and contrast in the liminal stimulus for vision. J. Exp. Psych., 10: 350-364, 1927.
   b. Ludvigh, E. Effect of reduced contrast on visual acuity as measured with Snellen test letters. Arch. Ophth., 25: 469-474, 1941.
   c. Lythgoe, R.J. The measurement of visual acuity. Med. Res. Council, Special Report No. 173. H. M. Stationery Office, 1932, 85 pp.
   d. Hecht, S. The relation between visual acuity and illumination. J. Gen. Physiol. 11: 255-281, 1928.

2. Crawford, J.S., Shagass, C. and Pashby, T. J. Relationship between visual acuity and refractive error in myopia. Am. J. Ophth., 28: 1220-1225, 1945.

3. Kempf, G. A., Collins, S. D. and Jarman, B. L. Refractive errors in the eyes of children as determined by retinoscopic examination with a cycloplegic. Pub. Health Bull. 182, Gov. Printing Office, Washington, D.C., 1928.

4. American Medical Assoc., Committee on Optics and Visual Physiology. Report on the Tests and Records of Visual Acuity. Sect. Ophth. A.M.A., 1930, 358-363.

Discussion:

Lt. Paul asked if it is expected that the letter-type acuity slides will be used in industrial organizations as well as in the Military Services.

Dr. Sloan replied that she was unable to answer the question. The letter slides were prepared for the specific use of the Military Services, but there is presumably no reason why they cannot be used by industrial establishments if they so desire.

Dr. Marquis asked if there is any disadvantage in releasing the letter-type acuity slides for use in industry.

Dr. Sloan replied that she could not see any disadvantage in the letter slides being made available to industry, since it is impossible to memorize the order of the letters. Dr. Sloan commented that she felt the letters are good tests of acuity and that she would like to see industrial organizations using them.

Dr. Marquis pointed out that there would be some advantage in releasing the letter slides for use in industry, since validation studies made in industry would be helpful to the Military Services in establishing visual requirements. For this reason, Dr. Marquis was particularly anxious to know if there were any disadvantages inherent in releasing the slides for civilian use.

Captain Smith commented that he could see no reason why the charts should not be released for civilian use. Captain Smith expressed some concern, however, that it would be possible for malingering to occur if the charts were available for civilian use.

Dr. Sloan pointed out that different orders of letters are available on different slides so that memorization of the letters is not likely to occur.

Dr. Wolpaw pointed out that he felt it very unlikely that the letter-type acuity charts would be made available for civilian use. Dr. Wolpaw noted that no one except the Government may purchase the machines used to administer the tests. Commercial concerns may only lease the machines so that the control of the machines is entirely in the hands of the producer. Dr. Wolpaw pointed out that the company has spent a great deal of time and money promoting the idea of checkerboard acuity tests, and he is sure they would not be likely to change to letter-type tests for use in the machines which are leased to civilian concerns.

Dr. Rose expressed concern for the fact that some of the letters in the acuity test slides represented mirror images of other combinations of letters.

Dr. Sloan pointed out that this defect in one of the preliminary forms of the acuity slides had been entirely remedied in the final form of the slides.

Dr. Uhlaner expressed some concern that letter charts are more susceptible to practice effects than other tests of visual acuity. Dr. Uhlaner reported that an analysis which was made of acuity charts of this kind exhibited practice effects after 8 practice trials, which amounted to as much as two lines difference. Dr. Uhlaner suggested that, for this reason, it might be disadvantageous if the letter charts were made available for civilian use, since certain examinees would then have had practice compared with other examinees. Dr. Uhlaner commented that the correlation coefficients Dr. Sloan reported were undoubtedly inflated by the deliberate selection of 3/4 of the population tested from among those with acuity below 20/20-. Thus, the correlation coefficients obtained from

such a population are considerably higher than one would obtain from the general population.

Dr. Sloan commented that discussion with the statisticians at Johns Hopkins had indicated to her that the correlation coefficients Dr. Uhlaner obtained in his studies are artificially deflated by the selection procedures employed.

Dr. Fry commented on one point which worried him in connection with the testing of visual functions with the machine-type tests. Dr. Fry stated that, in his opinion, the important things to test at near are astigmatism and ansimetropia. Dr. Fry commented that in the checkerboard test the difference in acuity obtained in the testing of the two eyes separately, provides a measure of ansimetropia, since both eyes focus the checkerboard target. Dr. Fry was concerned that in the Armed Forces Visual Screening Test of near visual acuity, each eye is tested separately, and is, therefore, likely to focus separately on the monocular target. The result would be that the measures of monocular acuity in the two eyes taken separately would not reveal the effect of ansimetropia in the same way that ansimetropia is revealed by the monocular tests with the checkerboard target.

Visual Acuity Requirements for Submarine Enlisted Personnel

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Abstract

This study undertook to determine the visual factors involved in all interior submarine tasks which an enlisted man may be required to perform.

It was found that distances from which visual signals are viewed within a submarine are such that standard acuity measurements taken at 20 feet are not predictive of performance of submarine tasks.

Visual angles subtended by critical cues are always larger than necessary for discrimination by 20/20 vision. This takes into account the larger visual angles required under the lower illumination found in submarines.

Clinical recommendations are that acuity of 20/30 measured at the distance of the task is minimum and that exophoria or more than 3 prism diopters of hyperopia of more than 3 diopters should be rejected.

Introduction

Since the submarine is a highly complicated mechanism it is essential that its crew be chosen with high standards of ability if it is to meet successfully the hazards of its element and prove an effective weapon. Present visual standards have been prescribed only in terms of acuity for distance. This is proper for those of the crew who perform deck duties and topside watches, but it does not give consideration to below deck jobs where the working conditions are entirely different.

The Manual of the Medical Department states that "the (visual) requirement for enlisted men of the seaman branch shall be 20/20 in each eye"..."For all other candidates the minimum vision shall be 15/20." In order to conform with the revision of procedures of 1 February 1949 which requires that "vision test scores shall be expressed as a fraction in which the upper number is the distance in feet from the targets, and the lower number is the value of the smallest test chart line read correctly" (e.g., 20/20, 20/30), the acuity value of the 15/20 original requirement is converted to 20/27. Since there is no 27 line on the chart, present practice is to estimate this acuity by requiring perfect reading of the 30 line and near correct reading of the 25 line. It should be noted that the tests in question are given at a 20 foot distance which is equivalent to "far" vision; no test is prescribed for other distances.

Consideration of the visual acuity requirement for submarine enlisted personnel poses several specific problems. First of all, a clear understanding must be attained of the nature of the visual tasks incident to the operation of the submarine. This will include such factors as the size and shape of the visual cues, the distance from which they are viewed, the contrast ratio between cue and background, and the level of illumination.

As the initial step in the present study we undertook to survey a submarine to determine the visual factors in all interior tasks which an enlisted man may be required to perform.

Such information must form the basis of a system of selection if it is to predict adequately the visual suitability of personnel for performance of such tasks.

As the second step, we have attempted to interpret the visual resolution requirements for various tasks in terms of approximate visual acuities. In this interpretation, approaches have been made, first, on the basis of experimental studies of acuity with various targets under controlled conditions, and second, on the basis of clinical experience with similar job requirements in other situations.

Procedure

Procedure of the survey consisted in obtaining a complete measurement of every instrument which serves as a visual indicator for the performance of some task, together with the range of distances and positions from which the cue must be noted, the illumination, contrast ratios, shapes, etc. The following information was obtained:

(a) Type of instrument: dials, vertical gauge (liquid column), "on" "off," bubble level, liquid column;

(b) Measurements on instruments: diameter, color, pointer-length, width, color, scale markings-width-interval, numeral-size-style, reflectances, illumination, operational distance;

(c) Judgment by operator: direction of pointer, position of pointer tip, position of pointer head, number, scale mark, ± limit, vernier match, off-on, red-green, position of bubble, position of column;

(d) Action executed by operator: manipulation of lever, etc., entering reading in log, vocal, hand or other signal.

Results

Table I shows the specific data obtained by a survey of one submarine, U.S.S. DOGFISH. Despite known variations within submarine of the Force, DOGFISH is, by inspection, considered to be a representative submarine as regards illumination and visual cues. The first section of the table attempts to identify in detail every task studied, its location, the man performing it, the action involved, and the name of the visual cue controlling the task. The second section gives a description of the visual cue and the measurements of the essential parts of each instrument, the distance from which it is viewed, the amount of illumination falling on it and the reflectance of its critical surfaces. Special factors to be taken into account are noted under "Remarks," While placement of instruments and illumination may differ on various boats, the principal data will remain comparable.

Table II summarizes the data with emphasis on the principal factors, namely, type of visual cue, working distance, angular subtense of cue, and brightness contrast. Under "Critical Visual Task" we have tabulated the critical discrimination cue for every instrument. This is the angle subtended by the smallest detail of the instrument that must be read to perform the operation.

Since visual acuity is directly dependent upon brightness of the discriminated object, equal angles from different cues do not present the same visual task. Each one is modified by its brightness. To reduce all measurements to a common basis we have multiplied each angle by a factor which changes it to an equivalent size in terms of visual acuity for a brightness of 12 fL. The formula for the correction is

$$A_c = A\frac{L_x}{L_{12}} \qquad (1)$$

in which A = the uncorrected visual angle

L_x = Lythgoe's acuity value at the brightness of the uncorrected visual angle

L_{12} = Lythgoe's acuity value at the brightness of 12 fL

A_c = the uncorrected visual angle.

The brightness conversion factor was determined as follows: From the data of Lythgoe (broken-C target) we read the minimum visual angle (a) at a brightness of 12 fL, and (b) at every brightness shown in our table. The minimum angle for every cue is multiplied by the ratio of the angle at the brightness of the particular cue to the angle at 12 fL. For example, the first measurement in Table II shows that a visual angle of 14 min. must be discriminated on the "Master Impulse Bottle Pressure" gauge when the brightness of the dial is 1.7 fL. According to Lythgoe the minimum visual angle at 12 fL is .53 min. and at 1.7 fL is .67 min. The ratio between these two minimum angles is .79. Multiply the measured angle of 14 min. by this ratio, .79 to obtain 11.1 min. This is the equivalent angle at 12 fL standard brightness, of 14 min. at 1.7 fL.

In every compartment, there is a wide range of minimum visual angles. Most tasks do not require fine visual discrimination. Only one task was found which depends upon a minimum angle as small as 1'. This consisted of a bright dot on a dark ground. Such a cue is visible at very small angles. Other than this the smallest resolution is a 2.2 min. visual angle (corrected for brightness) which occurs on two dials in the control room. All other visual cues subtend angles of 3' or greater.

The greatest distance from which a cue might be viewed is 102 inches, and this occurs only once. Of the 46 tasks, 31 are viewed at distances between 72 in. and 24 in. A few instruments, 11 out of 46, are read from 24 in. or less and may be considered near-vision tasks. Only two cues normally require a 12 in. distance.

Discussion

The visual cues which must be discriminated are varied and are only indirectly related to the standard ophthalmic measures of visual acuity. Rarely does a crew member have to read letters or numerals. Most frequently he must respond to some aspect of a dial. He notes the direction of a pointer, or the position of the spatulate end of a pointer, or the scale division indicated by a pointer.

Visual acuity scores in common use are based upon reading letters which are complex visual objects requiring resolution of grid-like patterns and discrimination of brightness, but include as well certain undefined components called "letter factors." While the Snellen "20/20" letters are constructed of strokes and serifs that subtend one minute at twenty feet, these letter targets by no means provide a measure of the resolution of details of other types of targets.

A comparison of the relative visual angles which can be discriminated in different

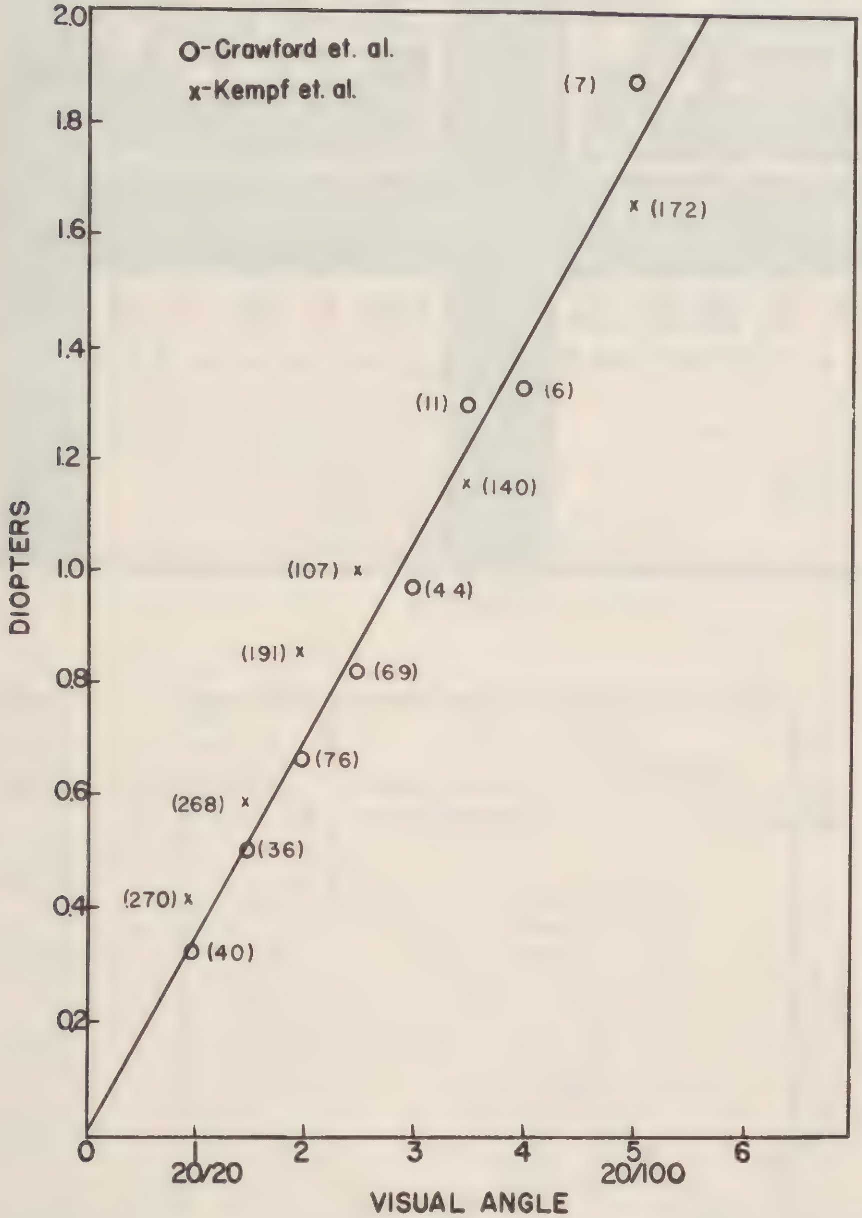
O-Crawford et. al.
x-Kempf et. al.
DIOPTERS
VISUAL ANGLE
20/20
20/100
(7)
(172)
(11)
(6)
(140)
(107)
(44)
(191)
(69)
(76)
(268)
(36)
(270)
(40)

Figure 1

Figure 2

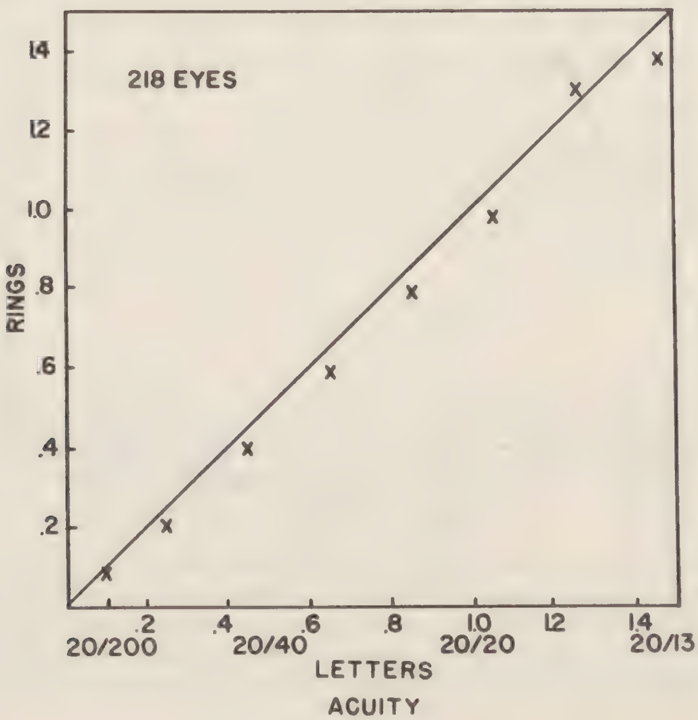

Figure 3

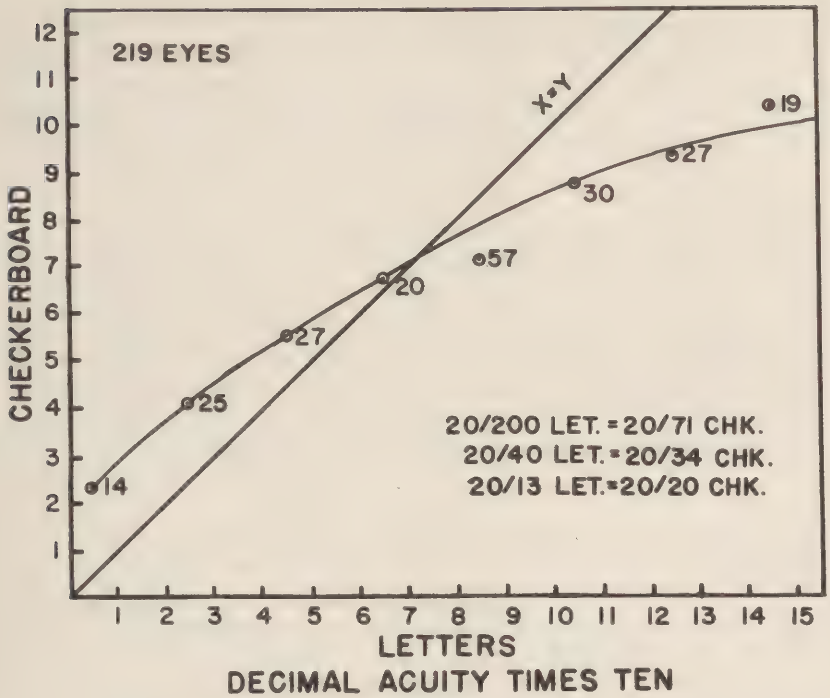

Figure 4

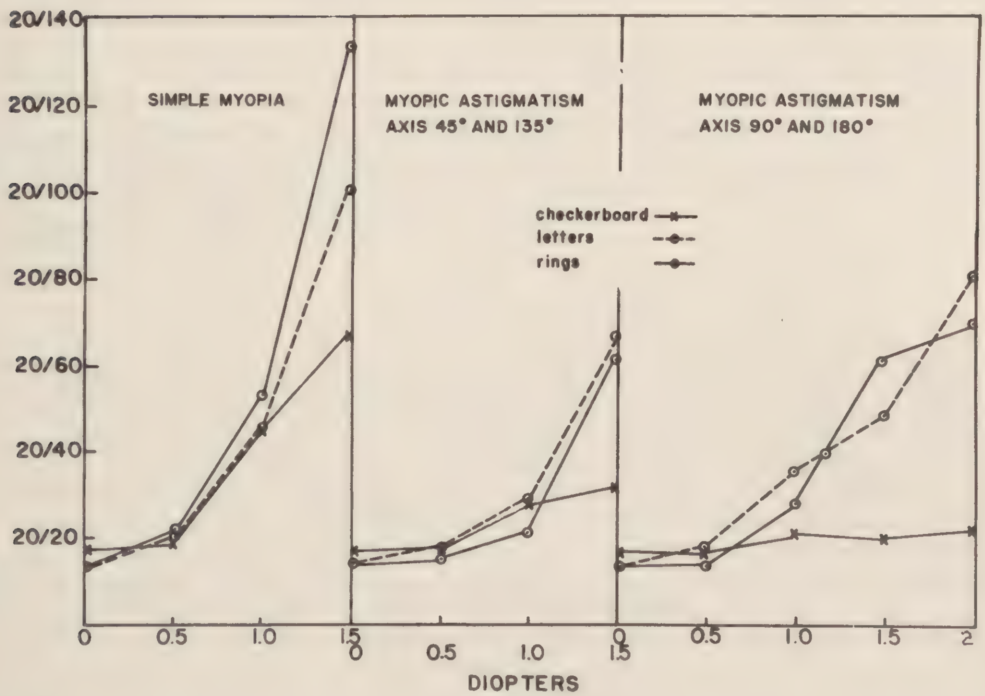

Figure 5

types of targets can be made from data derived from the AGO study* given in Figure 1. The data in this figure are the unit angles in various types of targets selected because of some comparability with devices which are employed on submarines. The unit for the line is its width; for the dot, its diameter; for the checkerboard, the side of the single checker; for vernier, the offset; and for letters, the width of the stroke. Data have been converted to straight line regressions, and all targets are plotted relative to the New London Letter Charts.

For example, men with an average AGO score of 10.50 (20/15+) who read New London Snellen type letters made up of 0.7 minute strokes, would just differentiate a checkerboard target with elements of 1.0 minute, but could detect a misalignment of 0.25 minute in a vernier task, and could easily resolve a .03 minute line when it was presented singly. Under test conditions, resolvable lines are 1/23 as thick as the stroke of resolvable letters. On the other hand, men whose AGO scores averaged 9.00 (20/40) who just read New London letters made up of 2 minute strokes, could differentiate a checkerboard target with elements of 1.8 minutes, could detect vernier misalignment of 1.008 minutes, and could resolve a line of .25 minutes.

Resolution of lines is particularly important because it appears in some form in most submarine tasks. The minimum critical angle on most dials is related to line resolution, either the line of the needle or the lines of the scale divisions. Of the 51 visual tasks studied, 28 involved dial readings. In every compartment but one, the task requiring the minimum visual angle involves a dial. The narrowest pointed or scale division in any compartment subtends an angle (2.2 min.) nearly 40 times the minimum resolvable by a man with 20/20 vision. However, scale divisions are not pure line resolution. Depending upon their length, their width relative to the space between, and their pattern relation to nearby markings, lines may acquire the perceptual characteristics of grids or checkerboards. If we so interpret them, the narrowest scale markings are still 80% larger than the angle required for 20/20 acuity.

Specification of 20 feet as the only distance to be used in acuity screening tests, seriously limits the applicability of the test results. While men whose acuity measures 20/20 at 20 feet will show the same acuity at shorter distances, many men who show less than 20/20 at 20 feet will achieve that acuity at the shorter distances typical in a submarine. On the other hand, many 20/20 men will suffer considerable discomfort from the continued accommodation at distances near 2 feet.

Clinical Interpretation

The minimal and optimal visual requirements for various industrial occupations have been the object of extensive ophthalmological study. Thousands of jobs in which visual acuity is an essential component have been analyzed in order to establish minimum job standards. Dr. Hedwig S. Kuhn, Secretary of the Committee on Industrial Ophthalmology and Dr. Newell C. Kephart of Purdue, are pioneers in this field of diagnosis and prescription. Upon consultation they offered to apply their information from the analysis of industrial jobs to the description of submarine visual tasks. Their initial analysis was made from the information furnished in Table I and was checked by Dr. Kuhn who made a trip to the Submarine Base, New London, for that purpose.

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*Adjutant General's Office. Studies in visual acuity, Washington, D.C. U.S. Government Printing Office, 1948 (PRS Rep. No. 743).

No critical factors appeared among submarine visual tasks to indicate any essential difference from visual tasks in industry. A generalization from the latter is that acuity of 20/30 defines a minimum below which visual hazards appear. Therefore, for submarine tasks 20/30 is recommended as minimum whenever visual discrimination is required. In these recommendations the fractional acuity value (e.g. 20/30) is used to specify an angular size of the target at the particular distance of the task. For example, 20/20 means resolution of 1.0 min. visual angle, 10/20 means resolution of .5 min. visual angle. Application of the suggested standards would require acuity tests for the specific distances. Except for emmetropes (possibly defined by 20/20 acuity), acuities measured at 20 feet do not give a basis for predicting acuities at other distances.

Further than this, visual hazards must be recognized, which are not disclosed by loss of acuity. The principal factor of this sort is exophoria at near, which may be accompanied by loss of visual efficiency.

A summary of the ophthalmic recommendations are shown in Table III.

Table III

Compartment	Assignment	Minimum Snellen	Acuity A.G.O.	Maximum Working Distance	Phoria Requirements
Torpedo Room	Torp. man	20/30	9.4	24" -70"	+ 3D and/or 3Δ exo near
	Gyro oper.	20/30	9.4	24" -70"	3Δ exo near
Manuevering Room	Ch. E. M.	20/30	9.4	24" -70"	3Δ exophoria
Conning Tower	Helmsman	20/20	10.	20'	3Δ exo
	Qtrmstr	20/20	10.	20'	3Δ exo
Control Room (port)	Chief	20/30 20/30	9.4 9.4	near (13") near (13")	3Δ exo
(stbd)	Snorkel	20/30	9.4	near (13")	3Δ exo
	Ch. Watch	20/40	9.	near (13")	
	Planesman	20/30	9.4	36"	
Engine Room		20/40	9.	near (13")	

In addition, hyperopia of more than +3 D. should be rejected.

Conclusions

Our survey of visual tasks within a submarine has brought out several facts about the visual discriminations required.

1. Distances from which visual signals are viewed within a submarine are such that standard acuity measures taken at 20 feet are not predictive of performance of submarine tasks. Acuity measurements at 12 inches, 24 inches and 72 inches would have positive predictive value.

2. Visual angles subtended by critical cues are always larger than that necessary for discrimination by 20/20 acuity, i.e., 1 minute visual angle on a Snellen chart or the equivalent in lines, dots, etc.

3. Clinical recommendations are that an acuity of 20/30 measured at the distance of the task is minimum, and that exophoria of more than 3 prism diopters and hyperopia of more than 3 diopters should be rejected.

Operational Significance of Visual Requirements for Submarine Personnel

Captain Thomas L. Willmon
U.S. Submarine Base, New London

The aircraft and the submarine are our two most vulnerable weapons of war, both by being insecure in their element and being dependent upon the ability and integrity of their men not only to engage the enemy but to sustain the crafts in their element.

Whatever the future submarines prove to be, the current types must surface and thus become even more vulnerable. The very small number of lookouts possible to employ and the impracticability of wearing glasses in the presence of almost continuous spray, renders the visual acuity of topside watches of extreme importance. For submarine officers, all of whom must stand topside watches, and for topside ratings, visual acuity below 20/20 for distance seems unacceptable in that the safest is none too safe.

As is generally customary, visual criteria are prescribed only in terms of acuity for distance. This must be determined for the 40% of the crew which may be involved in deck duties and topside watches, but in the majority of below deck work the maximal visual distances are within 72 inches, the testing for which no consideration has ever been given.

Every topside rating upon going below decks assumes below deck duties requiring visual acuity at near distances, thus indicating the need for testing <u>all</u> personnel for near visual acuity in addition to the customary determination of distance acuity.

Additionally, Dr. Hedwig Kuhn has directed our attention to the need for binocular instrumentation and testing. In the case of an alternating internal squint where an individual may have 20/15 in <u>each</u> eye (tested by occluding the other eye), the present tests and thinking fail to recognize that this person actually suppresses the vision of one eye and is for all practical purposes a one-eyed person.

The visual acuity requirements for below deck submarine operation, as determined in this study by measuring the visual angles subtended by operational cues, indicate that a visual acuity of 20/40 is tolerable for those ratings never having topside watches. The following considerations must be borne in mind however;

(1) At 20/40 or less the individual becomes a hazard; a below-decks submariner may wear glasses, but he must have sufficient visual acuity to enable effective action in crises without them. Crises are frequently unanticipated. A submarine and its crew make only one serious error.

(2) Incident to stress and particularly fatigue of long submarine patrols, visual acuity is expected to deteriorate.

(3) A visual decrement occurs in the submarine population, as indicated by a recent survey of the crew of three submarines, the crews of which had served in submarines from one to ten years. An experienced submariner who is found to have less than prescribed physical standards is not disqualified and transferred out of submarines unless his disability is considered to be hazardous. However, if standards were lowered to admit to the service those men who already are approaching a hazardous deficiency, the subsequent decrement could not be acceptable and more frequent physical disqualifications would result. As in aviation, men for the submarine force are accepted and trained with a service

expectancy in their specialty of 5-20 years. Physical disqualification subsequent to and resulting from a lowering of entrance requirements is seen to be uneconomical of time, money, and effort.

(4) Something less than 20/20 and 20/27 obviously is operationally acceptable, since submarines have been and are so operating. But since the limit of visual operational safety is approached while employing current visual standards, it is apparent that a lowering of entrance examination requirements would result in a state of unacceptable visual effectiveness of operating personnel.

Discussion:

Dr. Sloan commented that, if depth perception at near is not required, it should not make any difference whether both eyes are tested together or not.

Dr. Blackwell expressed concern as to the conclusions reached from Dr. Dimmick's study. Dr. Blackwell stated that it seemed to him somewhat dangerous to expect that adequate visual performance may be predicted by measuring the size of dial letters and then determining the visual angle equivalent for specifying acuity required for the task as the reciprical of the angle thus obtained. It is, of course, true that visual acuity involves the ability to discriminate critical detail corresponding to the size which is inverse to the acuity measure. However, the task of dial reading may be sufficiently different from the formalized acuity type test object so that the direct application of the acuity test notation to dial reading performance may not be justified.

Dr. Blackwell also expressed concern as to whether the results from industry indicating that 20/30 vision is sufficient for adequate performance may be generalized to the case of performance of submariners where the visual task may be somewhat different.

Dr. Dimmick replied that he was sorry that Dr. Kuhn was not present to comment upon the points raised by Dr. Blackwell. Dr. Dimmick stated that Dr. Kuhn was certain that conditions in the submarine are not unlike those encountered in industry. According to Dr. Dimmick, Dr. Kuhn considers vision below 20/30 to constitute an industrial hazard, so that 20/30 vision is to be considered minimal. Dr. Kuhn does not like the word "acceptable."

Dr. Sloan asked if there is any reason why submarine personnel cannot wear corrective lenses.

Dr. Dimmick stated that such lenses are worn in the submarine service.

Captain Smith expressed his opinion that perhaps the greatest problem occurs when a man must be called from below deck duty to deck duty as a lookout. Captain Smith questioned whether it is indeed true that for lookout purposes a man is more adequate with 20/20 than with 20/30 vision. Captain Smith pointed out that in lookout duty a man must first pick-up an object in peripheral vision and then examine it with foveal vision. Since the peripheral pick-up is very important, it is conceivable that the man with 20/20 might not be more adequate than the man with 20/30 vision.

Col. Byrnes asked if radar were not used for lookout purposes.

Captain Willmon stated that radar is used for lookout purposes.

Colonel Byrnes asked whether the use of radar does not reduce the necessity for lookouts.

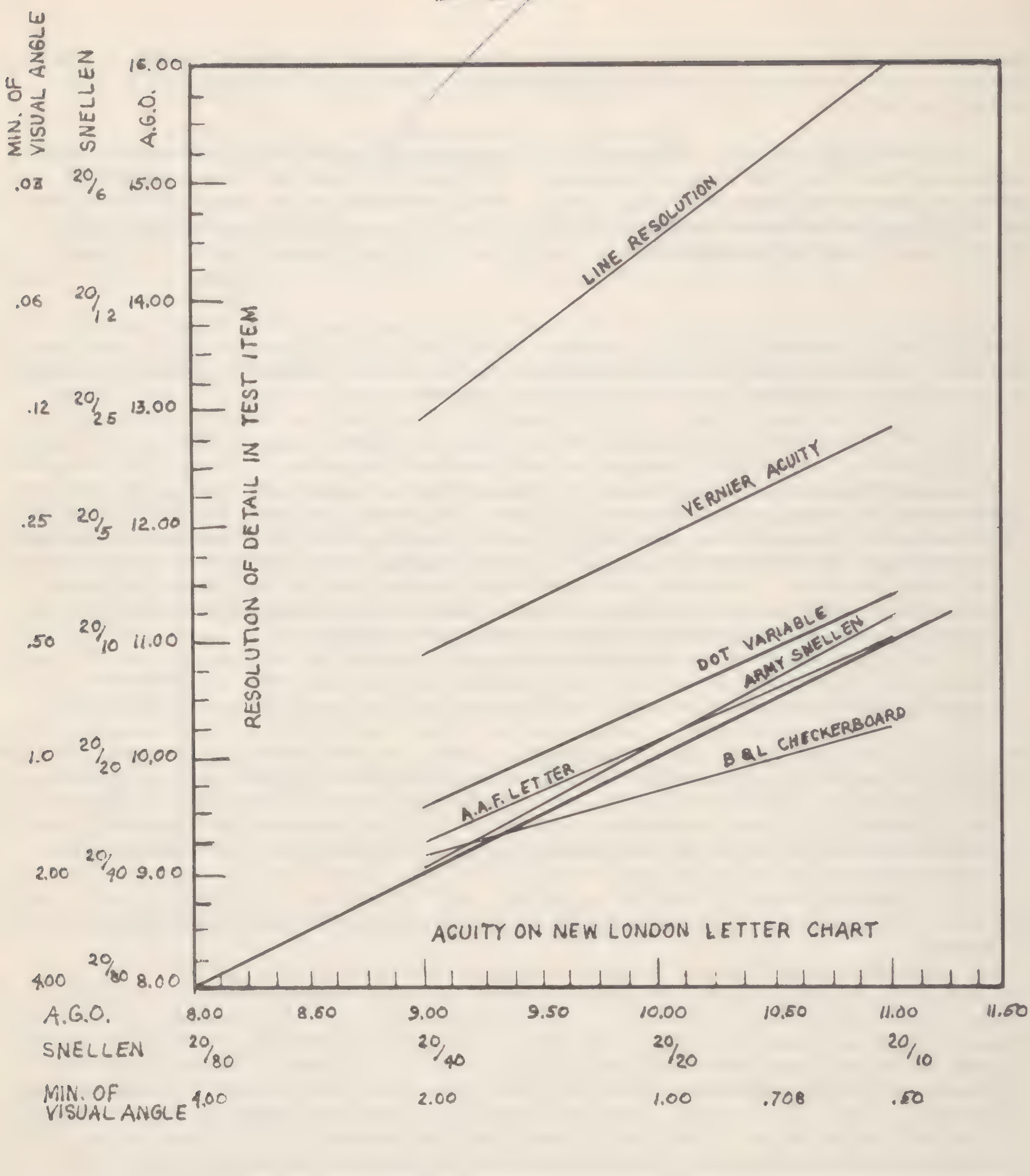

Figure 1. A comparison of the relative visual angles which can be discriminated in different types of targets. Data are derived from the A.G.O. study of acuity.

TABLE I

DATA ON VISUAL TASKS FOUND IN SUBMARINE "DOGFISH" SURVEY

Location (compartment)	Operator	Task: Action Executed	Task: Working Position	Task: Freedom of Movement	Task: Name of Gauge (visual cue)	Visual Cue – Description: Type	Detail Discriminated	Frequency of Reference	Non-visual Cues	Measurements – Distance from Operator (inches): Norm. Work.	Max. Work.	Dimensions (inches): Gross	Pnter	Numrl Hght	Scale Units	Reading Accuracy Required	Illumination (rigged white): Type	fc	Reflectance (per cent): Back-grnd	Mark (pntr, nmrl)	Remarks
Forward and After Torpedo Rooms	Torpedoman	open-close control	hand on valve	minimum	Master Impulse Pressure	dial	pointer	infrequent	none	-	24	3	.10	.25	.20	±.2	exter.	3.4	3	50	-
		open-close control	hand on valve	minimum	Individual Imp.Press.	dial	pointer	infrequent	none	-	102	3	.13	.19	.06	gross movement	exter.	1	3	50	4 to 6 dials. Dial under 35 fc has amber cover glass.
		open-close valve	hand on valve	minimum	Water Round Torpedo	dial	pointer	prior to firing	none	36	60	3	.10	.18	.10	.10	exter.	1.5	3	50	Face of dial partly obscured . Alternate cue sight gauge.
		cock-trip to close	hand on release	full	Poppet Valve Indicator	flag (opn-sht)	red-green open-shut	at time of firing	sound	60	72	1.7 x.9	-	.22	-	open-shut	exter.	.3	20	50	Insufficient illum. to distinguish colors. Alternate cue water to bilge
		watch gauge	any	full	Trim Tank Pressure	dial	pointer	infrequent	none	36	36	3	.13	.19	.06	.13	exter.	5			-
		flood tube	at breach doors	full	Sight Glass	water column	top column	flood or empty	sound	24	48	.5 x .9	-	-	-	full column	exter.	-	30	10	Alternate cues - tube pressure gauge, sound of water to bilge.
		check pressure	near tube	full	Hydraulic Pressure	dial	pointer	infrequent (see remrks)	none	48	72	3	.12	.31	.06	.5	exter.	1			400 and 600 positions numbered. check if door fails to open.
		open-close control	at manifold		Air Service	dial	pointer	when using air	none	24	36	3	.13	.19	.06	.13	exter.	4			-
		open-close valve	near tubes portside	full	WRT Volume	dial	pointer	when using tubes	none		36	3	.13	.19	.06	.13	exter.	2			-
		open-close valve	at manifold	full	Trim Tank	dial	pointer	when using tubes	none		48	3	.13	.19	.06	.13	exter.	2.5			-
		-	at tube	full	Tube Pressure Gauge	dial	pointer	whenever tube used	none	24	36	3	.06			.06	exter.				-
	Gyro Operator	matches dials by crank	seated before dials	minimum	Gyro angle Indicator	pursuit dials	radial marks	during preparation for firing	none	14	18	3.5	lines .02	.12	.20	vernior	exter.	16	2	60	Attempts to maintain vernier match
		set torp. running depth	between tubes	full	Torp. Depth Setting spindle	grad. spindle	scale	set depth	see remarks	20	24	2-2.5	lines .02	.19	.20	see remarks	exter.	.3 to .5	30	2	Crank cannot be disengaged unless ref. line coincides.
Maneuvering Room Starboard Side	Chief Electrician Mate	sets controls	at control levers	minimum	Annunciator	pointers & letters	pointer	frequent in maneuver	bell		30	6	.5	.25	1.	.5	exter.	6+	2	30	Bell rings and light flashes if response is mistaken.
		signals engine room	at control levers	full	Engine Room Telegraph	dial	pointer	frequent on maneuver	none	26	42	12 x 18		.25		-	self	-	2	50	-
		Read concent. hydrogen	at control levers	usually full	Hydrogen Detector	modified dial	pointer	frequent	none	60	60	3	.13	.13	.13	.25	self	-	55	6	Poor viewing angle; over right shoulder 135° from normal
		adjust blower	at control levers	usually full	Airflow Indicator	linear scale	pointer	frequent	none	60	60	2.5 x.13	.31	.31	.25	.25	exter.	1 to 3.7	50	-	Poor viewing angle obscured by case.
		-	at control levers	usually full	Bearing Oil Pressure	dial	pointer	frequent	none			4	.19	.25	.13		exter.	19 to 1.1	6	45	-
		-	at control levers	usually full	Battery Hookup	alternating signal	colored disc light	infrequent	none		72	1.5	1.5	-	-	on-off	self	-	-	-	Discs marked "Par" and "Ser" each a different color
		-	at control levers	usually full	Snorkel Indicator	on-off	red disc	-	auditory click		48	1.5	1.5	-	-	on-off	self	-	-	-	Red signal lights
		read pointers	at control levers	usually full	Maneuvering Panel	dial	pointer	very frequent	none	30	54	4	.13	.31	.13		exter.	2.3	35	3	19 dials grouped on panel
		log reading	at control levers	usually full	Shaft Revolutions	dial	pointer	frequent	none	30	43	8.5	.25	.25	.06	.09	exter.	1.3	3	60	-
Conning Tower	Helmsman	adjust heading	at wheel	limited	Gyro Repeater	pursuit dial	pointer	continuous	none	18	24	6	.03	.06	.185	.19	exter.	-	-	-	Self illuminated when rigged red
		read	at wheel	limited	Rudder Angle	dial	pointer	frequent	none	30	36	5.5	.06	.31	.13	.13	exter.	-			Self illuminated when rigged red
	Quartermaster	read and log	dead reck. trac.table	minimum	Target Range	bright dot	dot	constant on approach	none	-	24	2.25	.02	.12	.19	.5	exter.				-
		read and log	D.R.T.table	minimum	Target Bearing	bright dot	dot	constant on approach	none	-	24	2.25	.02	.12	.12	.5	exter.				-
		plot log	D.R.T.table	minimum	Position	black dot	-	constant on approach	none	-	12	-	.04	-	.1	.02	self				Poor visibility under red light
		read and log	-	full	Manometer	dial	pointers	occasionally	none	-	-	4.5	.04	.06	.10	.13	exter.				-
		read and set	D.R.T. table	minimum	Drafting machine	pursuit dial	white dot	occasionally	none	8	12	3.5	.02	.06	.04	.02	exter.				-
	Radar	read	at scope	minimum	Voltmeter and ammeter	dial	pointer	continuous	none	6-8				.12			self				-
		read	at scope	minimum	Azimuth ring	azimuth ring	sweep line	continuous	none	6-18				.25	.079		self				Numerals engraved [illegible] black background
	Sonar	read	at dial	minimum	Azimuth ring	pointer	pointer	continuous	sound	10-16				.25	.079		self				-
		read	at dial	minimum	Tuning	dial	knob of dial	continuous	sound	12							self				Awkward position (about 2 ft. from floor)
		read	at dial	minimum	Direction	dial	right-left	continuous	sound	10-16			.02		.098						-
Control Room Port	Auxiliary	turn wheel	at H.P. manifold	complete	Main Ballast Tank Blow	dial-hand signal	-	dive or surface	verbal	72	72	4.5	.09	.25	.06	.19	exter.	3	3	50	18 other gauges on this panel
		turn valve open	at H.P. manifold	complete	Snorkel Valve	dial	-	when snorkelling	verbal	13	13	4.5	.13	.25	.06	.31	exter.	2.5	2.5	70	-
		blow neg. tank	at H.P. manifold	complete	Negative Blow	dial	-	frequently	verbal	13	24	6	4 x .38	.31	.13	.18	exter.	8.	4	40	-
Starboard	Chief on Manifold	open vents	at hydr. manifold	restr.	Christmas Tree	light panel	red vs. green	constantly	none	36	36		none	none	none	none	self				-
	Auxiliary	trim boat	at trim manifold	complete	Trim and Discharge	dial	pointer	frequent	none	13	13	6	.38	.18	.13	.13		6	3	45	9 other gauges on this panel
		throws electrode switch	at board	minimum	Snorkel Board	on-off	red light	frequent	verbal	24	24				-	on & off	self				-
	Chief of Watch	-	at board	minimum	Hydraulic Pressure	dial	brass pointer	frequent	sound	13	13	3.5	.08	.25	.06	.12	exter.	3.5	3	45	Brass pointer on brass background
		-	at board	minimum	Air Pressure Manometer	dial	pointer	frequent	none	36	36	4.75	1.75 x .03	.18	.13	.18	exter.	3	6	60	-
	Planesman	turn wheel	at panel	none	Plane Angle	dial	pointer	frequent	none	36	36	6	.5	.25	.06	.06	self	4.8			-
		turn wheel	at panel	none	Ship Angle	bubble level	-	frequent	verbal	36	36	10 x .5	.5	.25	.31	.5	self	3			Two levels, one fine, one coarse. Green fluid
		turn wheel	at panel	none	Depth	dial	pointer	frequent	verbal	24	36	15	18	1	.38	.13	exter.	5	3	50	-
		turn wheel	at panel	none	Deep Depth	dial	pointer	frequent	verbal	24	36	8	.13	.5	.15	.13	exter.	3.5	3	50	-
Forward Engine Room	Throttleman	log readings	between engines	complete	Engine Lube Oil (Press.)	dial	twin pointers	once an hour	sound	48	-	4.5	.19	.19	.06	.08	exter.				12 gauges on same panel
		-	between engines	restr.	Generator thermometer	thermo-	mercury on steel	once an hour	none	36	-	4.5			.06	06	exter.	.6			-
		log	between engines	full	Engine heat	dial	pointer	once an hour	none	24		3 x 5	.06	.06	.13	.19	exter.	22			-
		read	between engines	full	R.P.M. indicator	dial	pointer	frequent	none	24		4 x5	.13	.19	.13	.13	exter.				-
		log and check	between engines	full	Engine Lube oil (temp)	dial	pointer	once an hour	none	24		4 x4	.19	.19	.13	.13	exter.				-

TABLE II

Analysis of Visual Cues in Terms of Visual Angle, Contrast Ratio and Critical Visual Task

Compartment	Visual Cues: Instrument (indicator, valve, gauge)	Type: Dial	Type: Other Types	Maximum Working Distance (inches) up to: 12	24	72	Visual Angle (Minutes): Pntr	Numrl Height	Scale Units	Accuracy Required	Higher Brightness fL	Contrast Ratio (Br diff) / low Br	Critical Visual Task: Minimum Angle (minutes)	Angle Corrected for 12 fL (minutes)
After and	Master Impulse Press.	x			x		14	36	29	29	1.7	.94	14	11.3
Forward	Indiv. Impulse Press.	x				102	4	6	2	(a)	.5	.94	4	2.6
Torpedo	WRT Pressure	x				x	6	10	6	6	.75	.94	6	3.9
	Poppet Valve		Red-Green			x		11			.15	.60	11	5.3
	Trim Tank Pressure	x				x	12	18	6	12			6	
	Sight Gauge		Vert. gauge			x				(b)		.67		
	Hydraulic Pressure	x				x	6	15	3	24			6	
	Air Service Forw'd	x				x	12	18	6	12			6	
	WRT Volume	x				x	12	18	6	12			6	
	Forward Trim	x				x	9	14	4	9			9	
	Torpedo Tube Press.	x				x	6			6			6	
	Gyro Angle		Pursuit dial		x		4	23	38		9.6	.97	4	3.7
	Torp. Depth Spindle		Grad. Spindle		x		3	27	29	(c)	.09	.93		
Maneuvering	Annunciater		Word indicator			x	57	29	1°55	57	1.8	.93	29	22.5
Room	Engine Room Telegraph		Word indicator			x		20				.96	20	
Starboard	Hydrogen Detector	x				x	7	7	7	14		.89	7	
Side	Airflow Indicator		Linear scale			x	18	18	14	14	.5		14	9.0
	Bearing Oil Press.	x					15	20	11		.5	.87	11	6.7
	Battery Hookup		Panel Board			x	1°12						72	
	Snorkel Indicator		Panel Board			x	1°47						107	
	Maneuvering Panel	x				x	8	20	8		1.26	.95	8	6.1
	Tachometer	x				x	18	18	4	6	.78	.95	4	2.9
Conning	Gyro Repeater		Pursuit dial		x		4	9	27	27	(d)		4	
Tower	Rudder Angle	x				x	6	30	12	12			6	
	Target Range Scale		Grad. spindle		x		3	17	27	1°12			3	
	Target Bearing Scale		Grad. spindle		x		3	17	17	1°12			3	
	Position Indicator		Black dot illum. field	x			11		29	6			6	
	Manometer	x												
	Drafting Machine		Pursuit dial	x			6	17	1	6			1	
Radar	Voltmeter & Ammeter	x						54					54	
	PPI Scope	x						48	15				15	
Sonar	Azimuth Ring							54	17				17	
	Tuning			x										
	Direction			x			4		21				4	
Control Room Port	M.B.T. Blow	x				x	4	12	3	9	1.5	.94	3	2.2
	Snorkel Valve	x			x		34	1°6	16	1°22	1.75	.96	16	12.5
	Negative Blow	x			x		1°40	44	19	26	3.2	.90	19	15.9
Stbd	Christmas Tree		Panel Board			x								
	Trim and Discharge	x			x		24	48	34	34	2.7	.93	24	23.2
	Snorkel Board		Panel Board		x									
	Hydraulic Pressure	x				x	21	14	16		.36	.93	14	8.2
	Air Pressure	x				x	3	17	12	17	1.8	.90	3	2.2
	Plane Angle	x				x	48	24	6	6			6	
	Ship Angle		Bubble level			x	48	24	30	48			24	
	Depth	x				x	17	1°36	36	12	2.5	.94	12	10.1
	Deep Depth	x				x	12	48	14	12	1.8	.94	12	9.7
Forward	Engine Lube Oil	x				x	14	14	4	6			4	
Engine	Switch to Generator		Vert. gauge			x			6	6			6	
Room	Pyrometer					x	9	9	19	27			9	
	R.P.M. Indicator	x				x	19	27	19	19			19	
	Engine Lube Oil	x				x	27	27	19	19			19	

(a) Gross movement
(b) Movement cue
(c) Alternate cue
(d) Conning Tower operating under red illumination.

Captain Willmon agreed that so long as radar is operative, lookouts are not required. He commented, however, that sole dependence upon radar can lead to disaster, and that we must always depend upon human vision for aid in detection. Captain Willmon pointed out that a submarine is a very vulnerable craft, and that, indeed, a rowboat supplied with a 50 caliber machine gun could sink a submarine. Captain Willmon commented that a man with 20/30 vision can perform very adequately as a lookout. He stated his concern, however, with lowering the standard to 20/30. With a 20/20 standard, there are many men in the service now with 20/30 vision. If the standard were lowered to 20/30, personnel might have far worse acuity, perhaps even as bad as 20/50. Captain Willmon emphasized, therefore, his belief that lowering the standard could be very harmful if carried much below 20/20.

A Portable Motion Parallax Tester

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During the Vision Committee Meeting of 12 November 1948, a motion parallax tester was demonstrated. The results of the measurements of said tester showed no correlation with measurements on the same subjects using the Howard-Dolman Test, which proves that different function was tested. While measurements with the Howard-Dolman Test gave no correlation with the landing ability of cadets (correlation coefficient + 0.057), the correlation coefficient of measurements with the motion parallax tester with the landing ability of cadets was significant though not great (+0.258). Apparently pilots do not use binocular simultaneous parallax for landing or - with the possible exception of formation flying - for other flight maneuvers, but may often use motion parallax for determination of depth. Motion parallax, therefore, should be used as a depth perception test for pilots either along or in combination with other tests.

Investigations reported in 1948 were done with laboratory type apparatus. For practical use in pilot selection a small test apparatus was developed.* It consists mainly of a translucent drum which rotates around a horizontal axis (figure 1). The drum is illuminated from within. Outside the drum arranged as a cylinder of 17 cm radius and coaxial with the drum is a set of 18 fixed rods. They give reference surface for 18 movable rods, which too are arranged as a co-axial cylinder. The radius of the latter cylinder can be varied by ± 6 mm. The examinee uses both sets of rods through a frame of 12 cm by 16 cm from a distance of 90 cm. The drum is rotated by a synchromous motor with 5 rpm. The relative position of the fixed and movable set of rods is changed by a cam (figure 2) driven by means of a differential gear, which the examinee or the examiner can actuate. A clutch prevents the examinee from finding the extreme positions of the rods by his mechanical rather than his optical sense. The examinee has the task to align the movable rods with the fixed rods. The errors are read off in the cam. The average error of the first 50 aviation cadets tested with the apparatus was 2.6 mm. Validation of the new test and combination with other depth perception tests is going on.

Discussion:

Dr. Hulburt asked whether it made much difference how bright the test field was in the motion parallax tester.

Dr. Rose replied that he had not found the brightness of the field to be very important. Dr. Rose stated that he had made tests at one-half and double the brightness normally used, and he had not found any difference in the results obtained.

Dr. Sloan asked whether correlations were being obtained between scores on the motion parallax tester and scores on various visual acuity tests.

Dr. Rose commented that he was testing only people who had 20/20 vision, since visual acuity is presumably one of the limiting factors in the successful ability to utilize motion parallax. Dr. Rose stated that he would not expect the correlation to be very high with visual acuity.

*The apparatus was built by Mr. H. Fleck, USAF, School of Aviation, Randolph AFB, Randolph Field, Texas

Dr. Sloan asked to what extent the test is subject to learning. She wondered whether two examinees with the same visual acuity might not be brought to the same limit of motion parallax with sufficient training.

Dr. Rose commented that although he had not measured the effect of training with the motion parallax tester, inferences from studies of stereoscopic vision indicate that there is a large training effect. Dr. Rose commented that, whereas 25-30% of the population cannot perform a stereoscopic task very well without training, this number drops from 3-5% with training.

Mr. Middleton asked whether Dr. Rose could not find a better word than "positive malingering." Mr. Middleton commented that this phrase reminded him of a "negatively sweet lemon."

Dr. Rose agreed that he did not like the term "positive malingering" either and suggested that "dissimulation" might be used instead.

Evaluation and Treatment of Hyperphoria

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Hyperphoria is a vertical deviation of the eyes controlled by fusion. When the two eyes are dissociated and fusion disrupted, the non-fixing eye deviates either upward or downward as the case may be. The amount of deviation of one eye is an expression of the deviation of both. If the right eye deviates upward, the left eye will usually deviate downward and vice versa. Thus right hyperphoria is equivalent to left hypophoria and left hyperphoria equivalent to right hypophoria. There are two exceptions to this statement. One is the pathologic condition of double hyperphoria which is presumably due to bilateral paresis of one of the vertically acting muscles; the other is a physiologic condition in which each eye when covered deviates upward, presumably due to the fact that monocular fixation is insufficient to keep both eyes on the same horizontal level. The latter condition is not a phoria at all but a monocular phenomenon which happens to be bilateral and is correctly called alternating sursumduction.

Total hyperphoria is composed of latent and manifest hyperphoria. Different tests of heterophoria convert varying amounts of latent hyperphoria into manifest hyperphoria which may be measured. Thus it is that different tests seldom give identical measurements on the same patient and would not be expected to do so. It is not a question of one test being any more or less accurate than any other test, but simply that different tests do different things. The Maddox rod test and the cover test are both reasonably satisfactory methods for measuring hyperphoria; so is the Troposcope or any major amblyoscope.

Incidence

When the Maddox rod test is used, about 35 per cent of patients seen in a routine ophthalmologic practice have hyperphoria of 0.5 prism diopter or more at either near or far[1]. Certainly 35 per cent of ophthalmologic patients do not have symptoms associated with their hyperphoria. Thus, it is not enough to know the incidence of hyperphoria in general but of hyperphoria that is associated with symptoms--of hyperphoria that is clinically significant.

In a series of 1,476 consecutive patients in a general ophthalmologic practice, 521 had 0.5 prism diopter or more of hyperphoria at either near or far. Of the 521, only 90 were found to have clinically significant hyperphoria. This is six per cent of the entire sam[ple]. Thus, while one out of every three patients may be expected to have some hyperphoria, about one out of twenty will have clinically significant hyperphoria. It is this twentieth pa-tient in whom we are particularly interested. How shall we evaluate his problem and what can be done about it?

Is The Hyperphoria Significant?

How can we tell whose hyperphoria is significant and whose is not? The patient with asthenopia should first have a careful refraction followed by the prescription of lenses and these should be worn more or less constantly during waking hours for a period of at least one month. If the asthenopic sysmptoms have disappeared at the end of this period, it is a reasonably safe assumption that any hyperphoria present is not clinically significant.

If asthenopic symptoms persist with the patient rendered emmetropic for a suitable length of time, clip- on prisms may be prescribed for suitable cases. If symptoms then disapper, it is reasonable to assume that the hyperphoria is clinically significant and prisms may then be incorporated in the permanent correction.

Many ophthalmologists hesitate to prescribe prisms for fear the manifest hyperphoria will increase in amount and require increasingly larger amounts of vertical prism to keep the patient free from symptoms. This certainly happens in some patients. I suspect that we are under the impression that it happens more frequently than it actually does. We tend to remember our therapeutic trials much longer than our therapeutic triumphs. Of 90 patients with clinically significant hyperphoria and vertical prisms prescribed, only 16 (18 per cent) had their hyperphoria increase and required more prism. Four-fifths of the patients with clincincally significant hyperphoria were relieved of their symptoms with vertical prisms and their hyperphoria did not increase with the passage of time.

Hyperphoria without Symptoms

The absence of symptoms associated with hyperphoria does not necessarily mean that the deviation is not clinically significant. It may mean that foveal suppression is present and, if this is true, the patient is in definite danger.

The first defense of the fusion mechanism in any losing battle against heterophoria is the development of foveal suppression. The moment foveal suppression begins to develop, symptoms begin to abate. When the former is well established, the patient is usually symptom-free. Thus, it is not enough to know that the patient with hyperphoria has no apparent symptoms. We must know why he has no symptoms. Is it because he has sufficient fusional reserve to handle the hyperphoria comfortably, or is it because his fusion mechanism has already begun to surrender and foveal suppression has been established?

The absence of symptoms associated with hyperphoria may be similar to a negative result from a tuberculin test--at least similar to its interpretation when I was in medical school. A negative tuberculin test was said to mean one of two things: either the patient had never been exposed to tuberculosis, or he had an overwhelming infection. When the fusion mechanism has been overwhelmed by a clinically significant hyperphoria and there are no symptoms, it is like a negative tuberculin test in a patient seriously ill with tuberculosis.

Which Cases Are Suitable for Prisms?

It has been said that vertical prisms may be prescribed for suitable cases. What are suitable cases? While very few cases of hyperphoria are truly concomitant, yet the more nearly concomitant is the hyperphoria, the more likely are vertical prisms to give relief. A moment's consideration will show why this is so.

A majority of hyperphoria cases have one vertically acting muscle that is the chief offender. Whether it offends by acting excessively or insufficiently is not germane at the moment. The fact remains that usually it is only one vertically acting muscle that is misbehaving. The vertically acting muscles have particular portions of the binocular field in which their action is most efficient. For example, the vertical recti of the right eye and the obliques of the left eye are chiefly concerned in the right half of the binocular field; the vertical recti of the left eye and the obliques of the right eye are chiefly concerned in the left half of the binocular field.

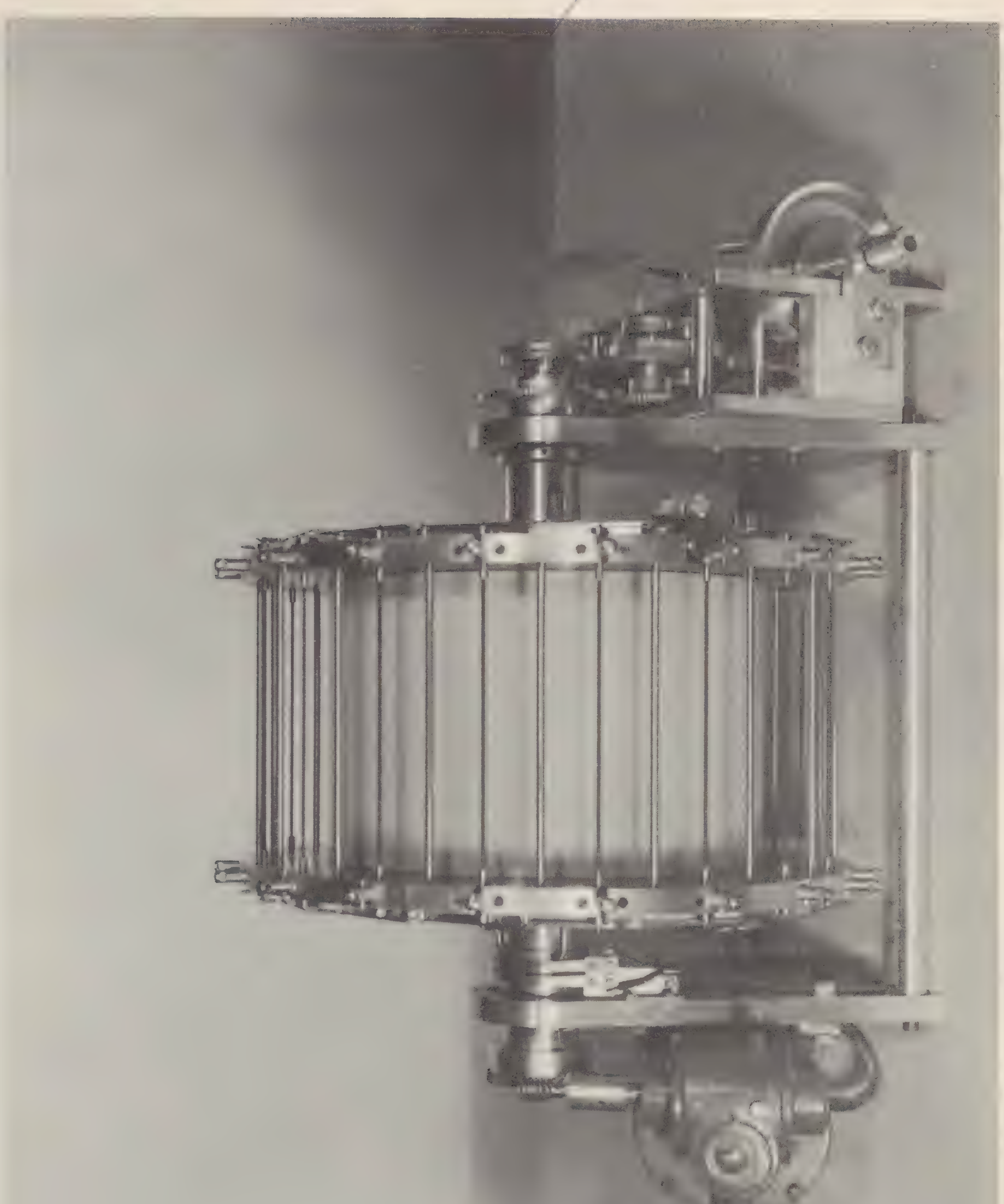

Figure 1 Portable Motion Parallax Tester

amount of prism with which he will be most comfortable. If the horizontal amplitude is greatest at a vertical setting of 3 prism diopters, then this is the amount of vertical prism to prescribe and not 5 diopters manifested on the test of hyperphoria.

There is often a difference of one prism diopter between near and far settings which give the greatest horizontal amplitudes at those distances. The patient's occupation will then be the deciding factor. A truck driver whose greatest horizontal fusion amplitudes are found with a setting of 4 diopters of vertical at far and with 3 diopters at near should obviously have 4 diopters prescribed; an accountant with the same findings should have only 3 diopters prescribed.

Method of Vertical Vergence

Some oculists prefer a determination of vertical vergences, using any difference between the two readings as the indication of how much prism to prescribe. Thus if a patient can overcome 5 diopters of prism base down before the right eye but only 2 diopters base down before the left eye, then the difference between 5 and 2, or 3 diopters, is the amount of vertical prism to be prescribed. This method will give a reasonably satisfactory percentage of good results but not as high as the method of studying the horizontal amplitudes with various amounts of vertical prism. In our hands, the method of vertical vergences is satisfactory between 60 and 80 per cent of the time, while the method of horizontal amplitudes is satisfactory close to 90 per cent of the time. The choice would therefore seem to lie with the latter. The orthoptist is well equipped to make such a vertical analysis and can thus perform a definite service to the ophthalmologist in his treatment of patients with clinically significant hyperphoria.

References

1. Scobee, R. G. and Bennet, E.A., Hyperphoria, Arch. Ophth., 43:458, 1950.

2. Posner, A., Prisms for Hyperphoria, Am. J. Ophth., 34:197, 1951.

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BRIGHTNESS OF THE TWILIGHT SKY

M. J. Koomen, R. Scolnik and E. O. Hulburt

Naval Research Laboratory

Several previous investigations (1-5) of sky brightness and polarization have been carried out by this Laboratory, which included measurements of points in the sky from the horizon to the zenith during the daylight hours for all altitudes of the sun from the horizon to near the zenith for the observer on the surface and in an airplane at various altitudes up to 38,000 feet. The measurements were made only for cloudless skies and for a fairly haze-free atmosphere. The brightness, but not the polarization, was also measured from the surface of many points of the sky during the night, after twilight had gone, at latitudes from -17° south to 68° north. Again, this was done for a sky free from clouds and an atmosphere fairly free from haze. During the period of twilight only the brightness of the zenith sky was measured.

In the present experiments the sky brightness, but not the polarization, was measured at the surface during twilight for a sky free from clouds and a fairly clear atmosphere. A recording photo-electric photometer of 1.5° field of view was used which automatically swept over the sky on meridians at bearings from the sun of every $22\text{-}1/2^{\circ}$. By means of a greenish filter on the photometer the spectral sensitivity curve was that of the light adapted eye. The photometer was calibrated to read candles per square foot against a non-selectively attenuated source at a color temperature of 2350°K, which ranged in brightness over nine orders of magnitude from that of the daylight sky to that of the night sky. With this calibration the photometer was used to read, or to give numbers to, the brightness of all places in the twilight sky during all the color changes from daylight to yellow, pinkish, greenish, etc., and to full night.

Twilight sky brightness records were made at our station in the country in Maryland during four clear evenings on January 18, 22, February 12 and March 9, 1951. From the records over a thousand points were plotted and average curves passed through them. The spread of the values of the four evenings was within a factor of two, the variations probably being due to variations in atmospheric clearness and perhaps to distant or invisible clouds. The average values from the smoothed curves are listed in Table 1. In the Table H is the altitude of the sun, positive and negative values referring to the sun above and below the horizon, respectively. The position of the place in the sky is designated by the altitude P above the horizon and the bearing Z from the direction of the sun. Thus $P = 90^{\circ}$ means the zenith, and $P = 30^{\circ}$, $Z = 90^{\circ}$ means a spot in the sky 30° above the horizon and 90° to the north or south of the direction of the sun. The sky brightness is the same in the two quarter-spheres on either side of the meridian through the sun.

In Fig. 1, the data of Table 1 are plotted in smooth curves for six places in the sky during a period beginning shortly before sunset and extending through twilight. The ordinates are the altitudes of the sun before and after sunset, and the abscissas are the brightness of the place in the sky marked on each curve. On the semi-logarithmic plot of Fig. 1, a portion of the curves are approximately stright lines of approximately the same slope. This was also true for the data of Table 1 for the other places in the sky. Therefore,

Table 1. Twilight sky brightness B in candles per square foot.

Zenith	
P	90°
H	B
+5°	43
+3°	35
0°	15
-3°	2
-6°	.06
-9°	$.0_{2}15$
-12°	$.0_{3}12$
-15°	$.0_{4}4$

Z = 0°			
P 10°	30°	50°	70°
B	B	B	B
1000	350	160	80
600	220	100	65
150	75	35	21
15	10	4	3
.7	.3	.13	.082
.03	$.0_{2}7$	$.0_{2}37$	$.0_{2}19$
$.0_{2}15$	$.0_{3}6$	$.0_{3}24$	$.0_{3}17$
$.0_{3}23$	$.0_{3}11$	$.0_{4}63$	$.0_{4}55$

Z = 22½°				
P	10°	30°	50°	70°
	B	B	B	B
	500	240	110	60
	300	180	75	50
	90	62	30	20
	13	7.5	4	2.5
	.65	.3	.1	.075
	.025	$.0_{2}7$	$.0_{2}32$	$.0_{2}17$
	$.0_{2}1$	$.0_{3}5$	$.0_{3}21$	$.0_{3}15$
	$.0_{3}17$	$.0_{3}11$	$.0_{4}62$	$.0_{4}53$

Z = 45°				
H	P 10°	30°	50°	70°
	B	B	B	B
+5°	260	165	80	50
+3°	175	130	60	42
0°	58	50	27	19
-3°	10	5.8	3.4	2.2
-6°	.35	.2	.08	.063
-9°	.015	$.0_{2}5$	$.0_{2}28$	$.0_{2}16$
-12°	$.0_{3}7$	$.0_{3}7$	$.0_{3}19$	$.0_{3}14$
-15°	$.0_{3}12$	$.0_{3}1$	$.0_{4}6$	$.0_{4}5$

Z = 90°				
P	10°	30°	50°	70°
	B	B	B	B
	94	80	60	45
	80	65	50	35
	35	32	22	17
	6	3.5	3	2
	.09	.09	.07	.05
	$.0_{2}45$	$.0_{2}34$	$.0_{2}2$	$.0_{2}15$
	$.0_{3}35$	$.0_{3}25$	$.0_{3}16$	$.0_{3}12$
	$.0_{4}7$	$.0_{4}75$	$.0_{4}53$	$.0_{4}47$

Z = 135°				
	P 10°	30°	50°	70°
H	B	B	B	B
+5°	150	100	63	48
+3°	100	70	50	39
0°	35	30	20	16
-3°	3	3	3	2
-6°	.07	.07	.07	.05
-9°	$.0_{2}3$	$.0_{2}25$	$.0_{2}2$	$.0_{2}13$
-12°	$.0_{3}25$	$0_{3}2$	$.0_{3}15$	$.0_{3}1$
-15°	$.0_{4}55$	$_{4}52$	$.0_{4}45$	$.0_{4}42$

Z = 180°				
P	10°	30°	50°	70°
	B	B	B	B
	170	110	66	50
	120	80	53	40
	40	35	23	19
	2	4	3.2	2
	.08	.07	.07	.05
	$.0_{2}3$	$.0_{2}25$	$.0_{2}2$	$.0_{2}15$
	$.0_{3}25$	$.0_{3}2$	$.0_{3}18$	$.0_{3}11$
	$.0_{4}53$	$.0_{4}5$	$.0_{4}46$	$.0_{4}4$

during a certain period of twilight, approximately for altitudes of the sun from about -3° to -11°, the entire twilight sky changed in brightness at approximately the same rate, and at the rate of about a factor of 10 for each 2° change in H.

The values of Table 1 agreed tolerably with corresponding measurements[3] made in Bocaiuva, Brazil, for an altitude of the sun H = 5°, the only altitude at which the two sets of data overlapped. Toward the sun the Maryland sky was brighter, and away from the sun, particularly near the horizon, was darker than the Bocaiuva sky. This indicated more haze or smoke in the Maryland sky than in the Bocaiuva sky, which seemed reasonable.

For low values of brightness of the sky in, or near to, the condition of full night, the values of Table 1 were less by about 40 percent than values measured with our other low brightness photometers.[2,5] The reason was that these instruments were calibrated for the dark adapted eye with a 2360°K color temperature source, whereas the photometer of Table 1 was calibrated for the light adapted eye with the same source. Since the night sky light is colored mainly by the green oxygen line 5577 A the 40 percent difference appeared to be due to the methods of calibration.

It is planned to repeat the series of measurements at another station on top of a mountain if possible.

DISCUSSION:

Mr. Middleton asked Dr. Hulbert where the square foot employed in the brightness definition, candles per square foot, should be located in the sky. Mr. Middleton suggested that sky brightness should be defined not in terms of candles per unit of area but candle per unit of area per steradian.

REFERENCES

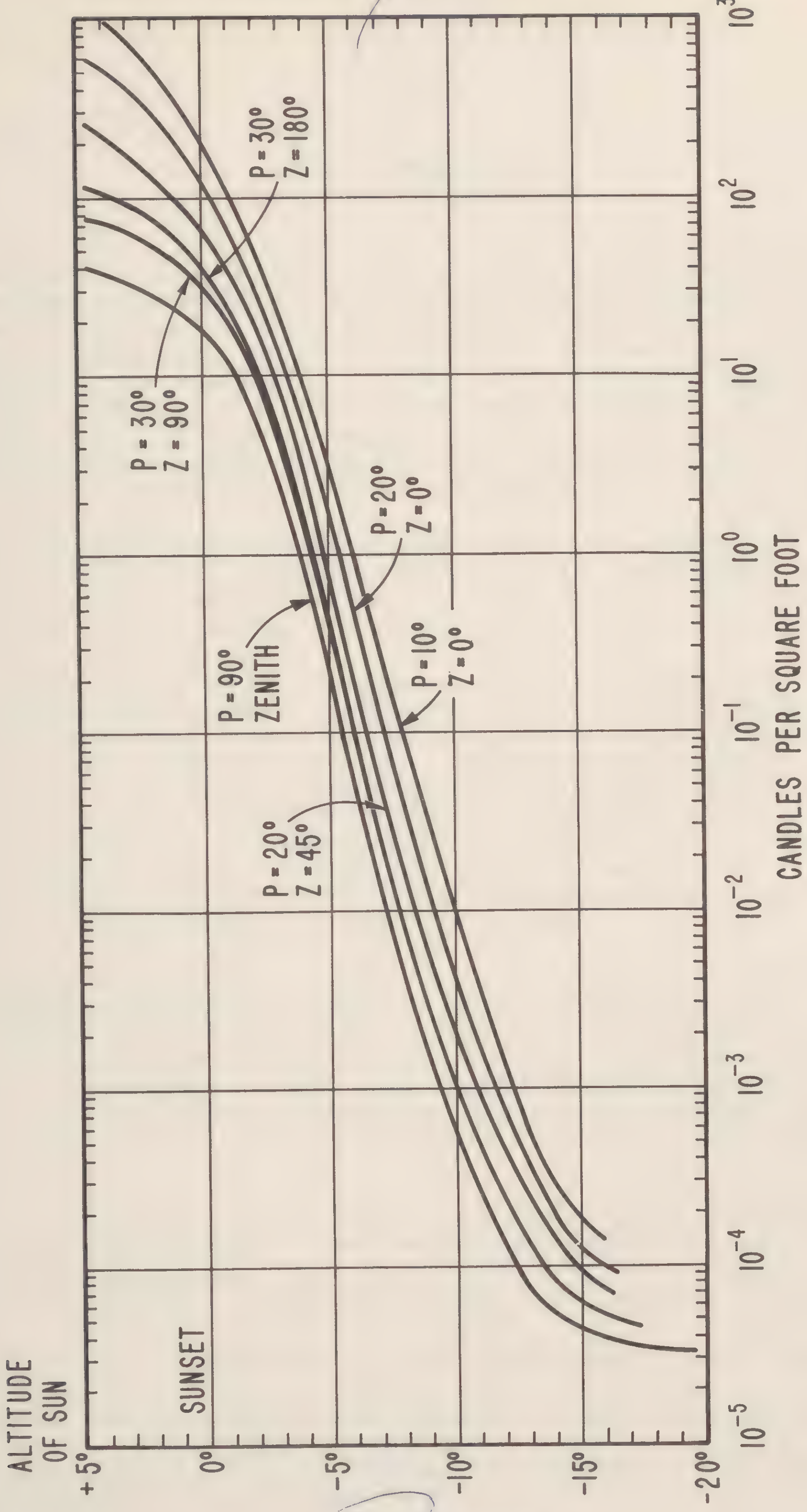
1. R. Tousey and E. O. Hulburt, J.O.S.A. 37, 78-92 (1947).

2. E. O. Hulburt, J.O.S.A. 39, 211-215 (1949).

3. R. A. Richardson and E. O. Hulburt, Jr. Geophys, Res. 54, 215-227 (1949).

4. D. M. Packer and C. Lock, NRL Report No. 3713, July 1950, "The brightness and polarization of the daylight sky at altitudes 18,000 to 38,000 feet above sea level"; to be published soon in the J.O.S.A.

5. Four brief papers in Trans. Amer. Geophys. Un. 31, 539-548 (1950).


ALTITUDE OF SUN
+5°
0°
-5°
-10°
-15°
-20°
SUNSET
P = 30°
Z = 180°
P = 30°
Z = 90°
P = 20°
Z = 0°
P = 90°
ZENITH
P = 10°
Z = 0°
P = 20°
Z = 45°
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
CANDLES PER SQUARE FOOT

Attenuation of Ultraviolet Light by the Lower Atmosphere

Synopsis

L. Dunkelman
Naval Research Laboratory

An important but largely unknown factor involved in the application of near and middle ultraviolet radiation is the attenuation of the atmosphere in the ultraviolet. Previous measurements of ultraviolet attenuation have all suffered from various limitations. Some investigators used line sources and so their results are not free from possible effects due to band absorption in the atmosphere. Then too, all the previous workers dealt with but one or two types of atmosphere, which were not always well defined. Vassy[1] did use a continuum and picked up the Herzberg bands of oxygen, but made measurements only for exceptionally clear air. We have attempted to make measurements over a longer period to cover all the commonly observed atmospheric conditions and have used a continuum.

The great majority of these measurements[2] were made on the campus of the California Institute of Technology, Pasadena, California, on 125 nights between March 1949 and April 1950 in collaboration with W. A. Baum.* During November and December, 1950, measurements were made at the Naval Research Laboratory, Washington, D.C.

The primary Pasadena data were obtained from a photographic system employing a xenon high-pressure arc as a source of intense ultraviolet continuum, an optical system for transmitting and returning two beams over paths of different lengths (path difference = 680 meters), and a quartz objective spectrograph. The attenuation over the two paths was determined by means of photographic spectrophotometry. The xenon arc system employed path folding mirrors. The source and spectrograph were at one location and this made it possible for one man at the spectrograph to operate the entire system. At first, this apparatus was operated nightly for a period of 72 consecutive nights in order to observe night-to-night variations. Following this period, observations were made at least weekly and under all extreme atmospheric conditions for one year.

In Washington it was planned to take data on only a few nights. Rather than setting up an elaborate path folding mirror system for one man operation, a simpler system but requiring three men was used. The objective spectrograph was employed as before, but the light source was a stable portable hydrogen arc lamp. Exposures were made with the lamp carried to two locations, one 876 meters further from the spectrograph than the other. The hydrogen arc system required relatively more stable air conditions than the xenon arc system because the exposures were much longer (15 minutes) and were not simultaneous over the two paths.

Fig. 1, is a microdensitometer trace of an original negative spectrogram taken in Washington on December 18, 1950. The Herzberg oxygen absorption bands between λ 2421 and λ 2684 can be seen clearly. These bands appear in all the long path spectra obtained in Pasadena and Washington. Another band system, from λ2800A to λ3150, can also be

[1] A. Vassy, Doctorate Thesis entitled "On the Atmosphere Absorption in the Ultraviolet," 1941, University of Paris.

[2] W. A. Baum, Doctorate Thesis entitled "Attenuation of Ultraviolet Light by the Lower Atmosphere," 1950, California Institute of Technology.

*Formerly associated with the Naval Research Laboratory and now with Mount Wilson and Palomar Observatories, Pasadena, California.

seen on this trace. This was identified as due to sulphur dioxide and was found in Washington on two of the three nights when observations were made. Sulphur dioxide bands were never observed in the many spectrograms taken in Pasadena.

The attenuation curves for Pasadena and Washington air are shown in Figures 2 and 3 respectively. Over most of the spectral region the attenuation coefficients are correct in absolute value to ± 0.05 km^{-1} or less. The 0_2 and SO_2 bands are not shown on these curves since they are relatively weak. In order to include them meaningfully, it would have been necessary to photograph the bands at many times the present resolution, which is of the order of 1 Angstrom. The attenuation curves have been drawn smooth through the regions of these bands by selecting data between the bands. In each of these figures a curve of calculated Rayleigh scattering coefficients is shown for comparison. All the curves are identified with a handy tag, i.e., a value for meteorological range.

In these experiments it was not practicable to measure simultaneously both the visible and the ultraviolet regions. It was impossible to obtain accurate attenuation data in the visible region with equipment using the relatively short paths, as required for work in the ultraviolet. On the other hand, it was important to tie in the ultraviolet attenuation data with the meteorological range. This was done as best we could with available equipment. The "Loofah Hazemeter"[3] was available for part of the time; it gave an indirect measurement of the attenuation coefficient, σ, at λ 5500, from which the meteorological range was calculated from the relation[4]

$$MR = 3.912/\sigma$$

When Loofah was not available, we simply extrapolated the ultraviolet curves into the visible using the Linke-Borne formula described by Middleton.[5] A Linke-Borne formula curve, passing through the point at 5500A determined by Loofah, in most cases joined the blue end of the experimental curve well in both slope and absolute value.

Figure 2 comprises typical attenuation curves for Pasadena. They represent a large variety of atmospheric conditions with meteorological ranges extending from 100 km to 0.4 km. There are many peculiarities in the curves; these were real, and varied from night to night. Below 2500A the curves were apt to cross one another, or at least to approach a common value. On nights of the same meteorological range, the curves were frequently found to differ greatly in these respects.

In Fig. 3, the Washington data are shown. The attenuation curve from Vassy for exceptionally clear air containing 0_3 is included for comparison. The similarity in shape of the November 6 curve to that of Vassy's suggested the presence on this date of ground ozone whose absorption became detectable at roughly λ 2900 and increased to shorter wavelengths. Calculations based on the ozone coefficients of Ny and Choong indicate that ozone may have been present in roughly 3 parts in 10^8. The concentration of SO_2 during the nights of December 13 and 18 has not yet been determined.

From analyses to date a number of conclusions have been drawn among which are:

1. Coefficients of attenuation of ultraviolet light by the lower atmosphere are now available for a variety of atmospheric conditions. Although these data may serve as a

[3]H. Richard Blackwell, "Report of Progress of the Roscommon Visibility Tests," Minutes and Proceedings of the 23rd meeting of Vision Committee.

[4]Seibert Q. Duntley, J. Opt. Soc. Am. 38, 179 (1948).

[5]W. E. K. Middleton, "Visibility in Meteorology" (University of Toronto Press, 1941.)

good guide, their usefulness is limited because of the following considerations:

(a) The data represent, in the most part, conditions in one place (Pasadena) where industrial air polution and smog frequently prevail.

(b) The fields in the systems used were extremely limited, (less than one degree), and application to optical systems employing larger fields may lead to sizable errors as one goes to shorter wavelenths or employs wider fields of view.

2. Except for the regions of the Herzberg 0_2 bands, 2421 to 2684 Angstroms, and the possible SO_2 bands, the attenuation of air is a smooth (sometimes slightly wavy) function of wavelength down to 2300 Angstroms (the limit of these measurements), and can validly be measured using sources emitting line radiation. This conclusion lends more weight to the data of several previous and current investigations using line sources.

3. The hydrogen arc-objective spectrograph system has been established as providing a convenient method to obtain ultraviolet attenuation data in the field.

4. Sulphur dioxide is present in the atmosphere around Washington as evidenced by the SO_2 absorption bands in spectrograms taken at NRL on two different nights. These bands were not present in the data taken in Pasadena.

5. The crossing of curves and the differences in the ultraviolet for nights of the same meteorological range make it impossible to set up a formula, at least of any precision, relating the spectral attenuation of the atmosphere in the ultraviolet to the attenuation in the visible as determined from meteorological range.

Most of our data have been plotted in terms of attenuation coefficient per kilometer. In applying these data it is frequently more convenient to think in terms of ranges in sea miles and atmospheric transmission per sea mile. Accordingly, we have prepared Table 1, in which are listed some typical numerical values of visible and ultraviolet transmission per sea mile corresponding to several different kinds of weather. On a night of light haze, for example, the transmission per sea mile ranges from roughly 50% in the middle of the visible spectrum (λ5500) to 10% at λ 3000, and to less than 0.2% at λ 2400. In the case of the first of two clear nights shown, the transmission varies from 70% at λ 5500, to 15% at λ 3000, and to 0.2% at λ 2400, whereas during the other clear night the respective transmissions are 70%, 28% and 0.5%; the first night was smoggy and the other quite clean. In the exceptionally clear night the transmission in the visible through the middle ultraviolet remains high, being 91% at λ5500, 68% at λ3500, 51% at λ 3000, and then drops rapidly at shorter wavelengths. At λ 2600 the transmission is 6%, and is less than that on the smog free clear night. This is probably due to the presence of ozone during the exceptionally clear night chosen.

The Naval Research Laboratory is extending the investigation of atmospheric attenuation to tropical and sub-tropical regions. Arctic and sub-arctic regions are under consideration.

The Visibility of Submerged Objects II

Seibert Q. Duntley

1. Introduction

In the first part of this paper (see Minutes of the 27th meeting, p. 61) it was stated that the apparent contrast (C) of any submerged object viewed from above the water surface is related to the inherent contrast of the object by the relation:

$$C = C_o \left(1 + e^{-1000(\tan^2 \phi_T)/S}\right) \left(1 + \frac{s_\alpha \, r_\alpha \, b_\alpha}{b_{w_1}}\right)^{-1} \left(e^{-3.912\, d \sec \alpha' / v_{\alpha'}}\right) \qquad (1)$$

The first bracketed term, which specifies the reduction of apparent contrast caused by time-varying refraction resulting from wave action, was fully discussed in the first part of this paper. It remains to consider the second and third bracketed terms. These relate respectively to contrast reduction caused by reflection processes and to contrast attenuation by water throughout the path of sight from the object to the surface.

2. Derivation of the Third Term

An experimental investigation of the reduction of contrast by water was conducted at Diamond Island during the summer of 1948, and the results were reported at the 23d meeting (see Minutes 23d meeting p. 123). It was found: (1) that luminous density decreases exponentially with depth; and (2) that the apparent contrast of any object is exponentially attenuated with distance along any path of sight through water, the attenuation coeficient varying with the inclination of the path but not with the position of the sun. Further underwater experiments in 1949 showed that along horizontal paths of sight the attenuation coeficient for contrast equals the attenuation coeficient for a directed beam of light, i.e. the contrast transmittance of a horizontal path equals the beam transmittance of the same water. This observation, coupled with the observation that no departures from exponential variation of apparent contrast are found even in the case of positive inherent contrasts greater than ten, supports the thesis of Middleton that all objects are detected only by rays which encounter no scattering processes between the object and the eye.

The experimental results just described have provided the basis for a new theory of the reduction of apparent luminance by water. This new theory leads to the following relation between the apparent luminance B_R of a submerged object seen at distance R and the inherent luminance B_o of the same object seen close aboard:

$$B_R = \frac{\sigma q_o}{\beta + k \sin\theta} \left\{ e^{+k(R\cos\alpha' - d_T)} - e^{-(\beta R + k d_T)} \right\} + B_o e^{-\beta R} \qquad (3)$$

where the luminous density q_d at depth d is given by

$$q_d = q_o e^{-kd} \qquad (4)$$

and where: σ is the scattering-rate coeficient for the path of sight which is inclined at an angle α' with the vertical, d_T is the depth of the target, and β is the attenuation coeficient for the beam transmittance of the water. For horizontal paths of sight $(\alpha' = \frac{\pi}{2})$ equation (3) reduces to a form identical with Koschmieder's equation for the reduction of luminance along horizontal paths of sight through the atmosphere.

The apparent contrast of any submerged target against its deep water background may be found from equation (3). The inherent contrast C_o is related to the apparent contrast C_R

by the relation:

$$C_R = C_o e^{-(\beta + k \cos\alpha')R} \tag{5}$$

It will be noted from equation (5) that the optical properties of water, as they affect contrast, may be described by means of the two constants β and k. It is fundamental that two independent constants are required to specify the properties of an optical material possessing absorption and scattering.

As pointed out at the 23d meeting, conceptual and computational convenience is served by the introduction of a quantity to be called the hydrological range. This is the distance, measured along the path of sight, for which the contrast transmittance is two percent. Thus:

$$\overset{N}{\beta} = \ln\ 50/v_{90} \tag{6}$$

Equation (5) can be written in terms of the hydrological range $v_{\alpha'}$ as follows:

$$C_R = C_o e^{-(\ln 50)R/v_{\alpha'}} \tag{7}$$

Combining (5), (6), and (7) and solving for $v_{\alpha'}$:

$$v_{\alpha'} = \frac{v_{90} \ln 50}{\ln 50 + kv_{90} \cos\alpha'} \tag{8}$$

Recalling that $R = d \sec\alpha'$ and that $\ln 50 = 3.912$, the contrast transmittance (C_R/C_o) for the path of sight is seen to be:

$$C_R/C_o = e^{-3.912\, d \sec\alpha'/v_{\alpha'}} \tag{9}$$

This is the third bracketed term in equation (1).

3. Derivation of the Second Term

The subject of sky reflection by a moving water surface has already been discussed in the first part of this paper, wherein a "sky-factor" s_α was defined (see equation 10, part I) by the relation

$$s_\alpha = \frac{\int_0^{\pi/4} r_\phi\, B_\alpha\, d\hat{t}_\phi}{r_\alpha\, B_\alpha} \tag{10}$$

where the denominator represents the reflected luminance of the sky when the water is calm and the numerator represents the time averaged reflected luminance of the sky when the sea is roughened by wind.

The time averaged apparent luminance of the surface of the sea is derived from two sources: surface-reflected skylight or sunlight $s_\alpha r_\alpha B_\alpha$; and luminance upwelling from the depths B_{w2}. Thus the apparent luminance of the sea may be written $(B_{w2} + s_\alpha r_\alpha B_\alpha)$.

If the luminance upwelling through the surface of the sea from the direction of the submerged object is B_2, the apparent contrast of the submerged object is, by definition:

$$C = \frac{(B_2 + s_\alpha r_\alpha B_\alpha) - (B_{w2} + s_\alpha r_\alpha B_\alpha)}{(B_{w2} + s_\alpha r_\alpha B_\alpha)} \tag{11}$$

Equation (11) may be rewritten:

$$C = \left(\frac{B_2 - B_{w2}}{B_{w2}}\right) \left(\frac{B_{w2}}{B_{w2} + s_\alpha r_\alpha B_\alpha}\right) \tag{12}$$

Let the upwelling apparent luminance of the sea as seen from just beneath the surface be represented by B_{w1}, and let B represent the upwelling apparent luminance from the direction of the target. Then:

$$B_2 = B_1 t_{\alpha'} (1 - r_s R_w)^{-1} \tag{13}$$

and

$$B_{w2} = B_{w1} 5_{\alpha'} (1 - r_s R_w)^{-1} \tag{14}$$

where $t_{\alpha'}$ is the Fresnel transmittance of the water surface, r_s is the emergent reflectance of the water surface for the prevailing optical sea-state S, and R_w is the reflectance of the deep water (defined as the ratio of upwelling to downwelling flux). The term $(1 - r_s R_w)^{-1}$ is the sum of the infinite series of interreflections which occur between the surface of the water and the water beneath.

If equations (13) and (14) are substituted in the first bracketed term of equation (12), the term reduces to $(B_1 - B_{w1})/B_{w1}$. But this is, by definition, C_R as used in equations (7) and (9). Thus, equation (12) may be written:

$$C = C_R \left(\frac{B_{w2}}{B_{w2} + s\ r_\alpha B_\alpha}\right) \tag{15}$$

Convenience is served by rewriting equation (15) as follows:

$$\frac{C}{C_R} = \left(1 + \frac{s_\alpha r_\alpha B_\alpha}{B_{w1}}\right)^{-1} \tag{16}$$

The quahtities B_α and B_{w1} are absolute values of luminance throughout the foregoing derivation, but since they appear only as a ratio equation (16) relative values on any scale will serve equally well. Experimental convenience is served if quantities $b_\alpha = 1\ B_\alpha/E$ and $b_{w1} = B_{w1}/E$ are substituted, where E is the illuminance on a horizontal surface at sea level. The right-hand member of equation (16) will now be recognized as identical with the second bracketed term in equation (1). It is the contrast transmittance of the surface of the sea.

The derivation of equation (1) is now complete, but before it can be used for the prediction of the apparent contrast of submerged objects, a relation is needed between the relative upwelling luminance of the sea (b_{w1}) and parameters which may be readily determined. Theoretical and experimental work too lengthy for inclusion in this paper has yielded the following equation:

$$b_{w_1} = (n^{-2} t_\theta (1-y) + t_1 y)(1 - r_s R_w)^{-1} R_w \tag{17}$$

where: n is the refractive index of sea water, t_θ and t_1 are Fresnel transmittances for sunlight and skylight respectively, and y is the fraction contributed by skylight to the illuminance on a horizontal plane at sea-level. It will be seen from equations (1) and (17) that the appai ent contrast of any submerged object will be greatly affected by the altitude of the sun, for this controls both t_θ and y. The value of y is also profoundly influenced by the presence of clouds and atmospheric haze; it represents a second datum on the state

of the sky, independent and in addition to the value of s_α measured by the sky-state meter previously described.

A further discussion of the meaning of equation (1) and its application to calculations of the visibility of submerged objects will be given in part III of this paper.

ATMOSPHERIC TRANSMISSION - PER SEA MILE

Meteorological Range (sea miles) / λ	6 (light haze)	11 (clear)		43 (exceptionally clear)
5500 A.U.	0.52	0.70	0.70	0.91
4500	0.44	0.64	0.68	0.84
4000	0.33	0.45	0.63	0.77
3500	0.26	0.36	0.51	0.68
3000	0.10	0.15	0.28	0.51
2800	0.057	0.082	0.18	0.23
2600	0.025	0.029	0.085	0.057
2400	0.0016	0.002	0.005	0.010

TABLE 1

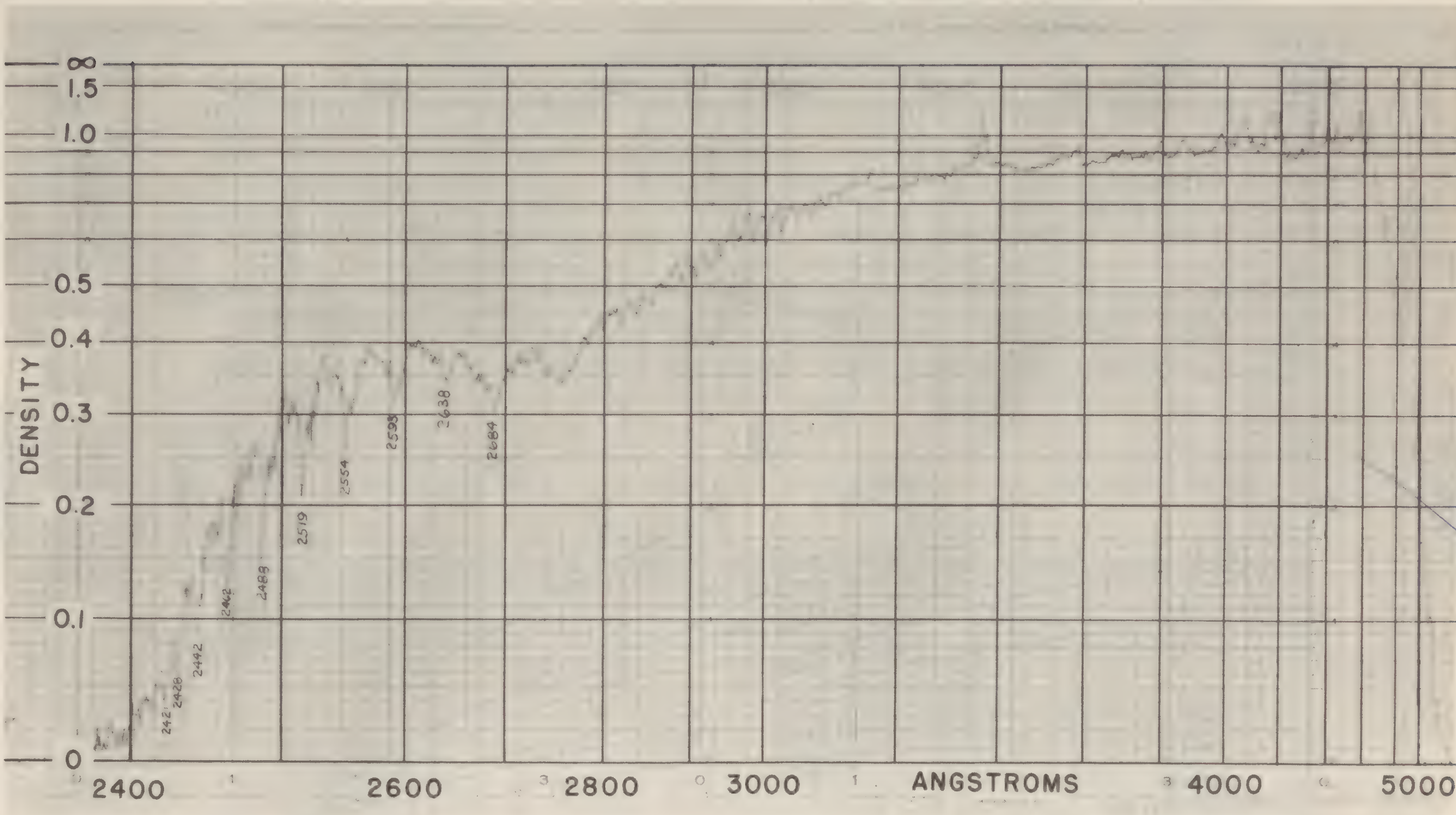


FIGURE 1. Microdensitometer trace of the hydrogen arc spectrum photographed over a path length of nearly one kilometer in Washington on December 18, 1950. The Herzberg 0_2 absorption band heads are labelled. The SO_2 bands appear between 2800 and 3150 Angstroms. Eastman 103-0 film, whose sensitivity begins to fall rapidly at 4500 Angstroms, was used.

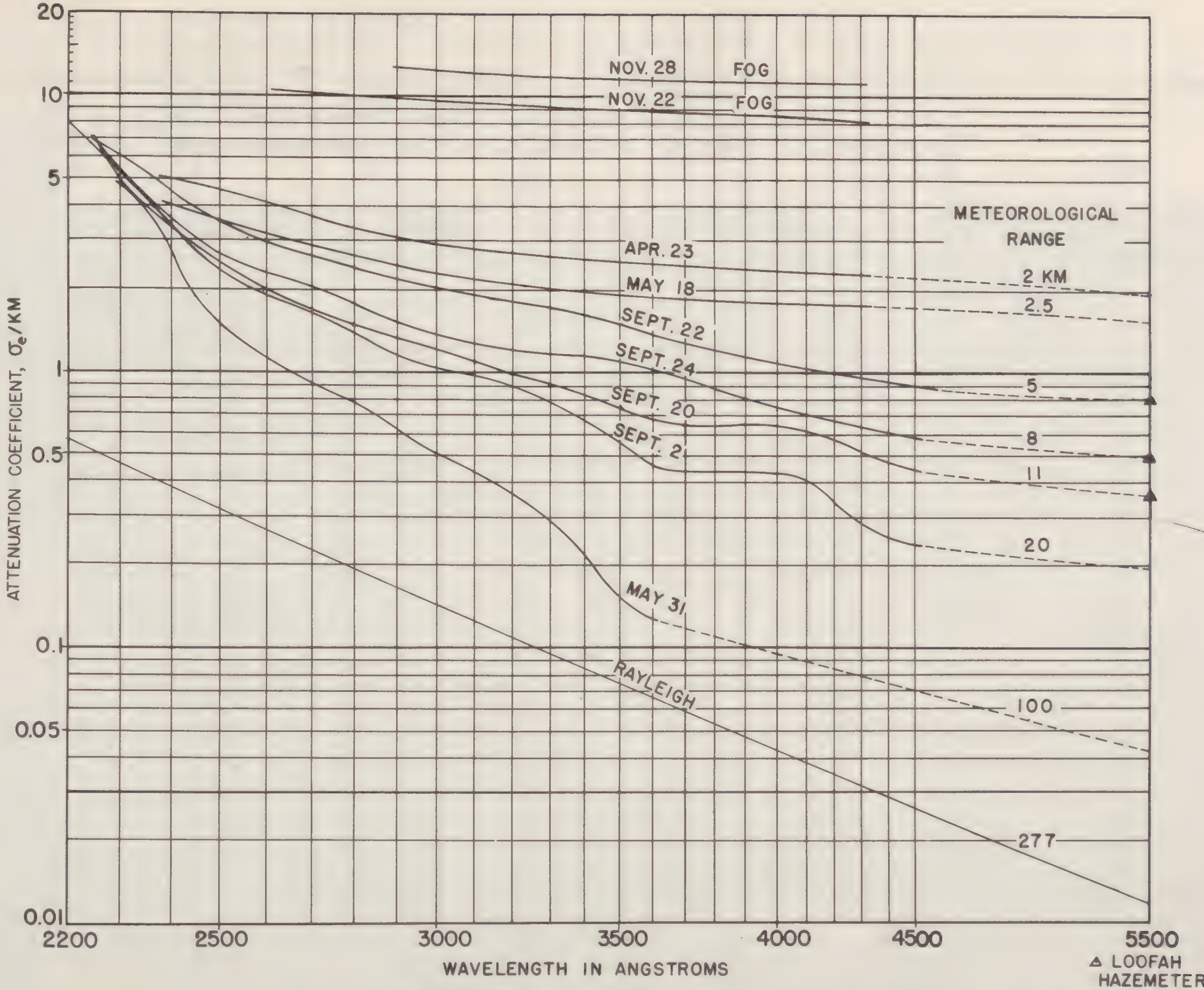


FIGURE 2. Typical ultraviolet attenuation curves representing different atmospheric conditions at Pasadena, California. These data were obtained from spectrograms taken in 1949.

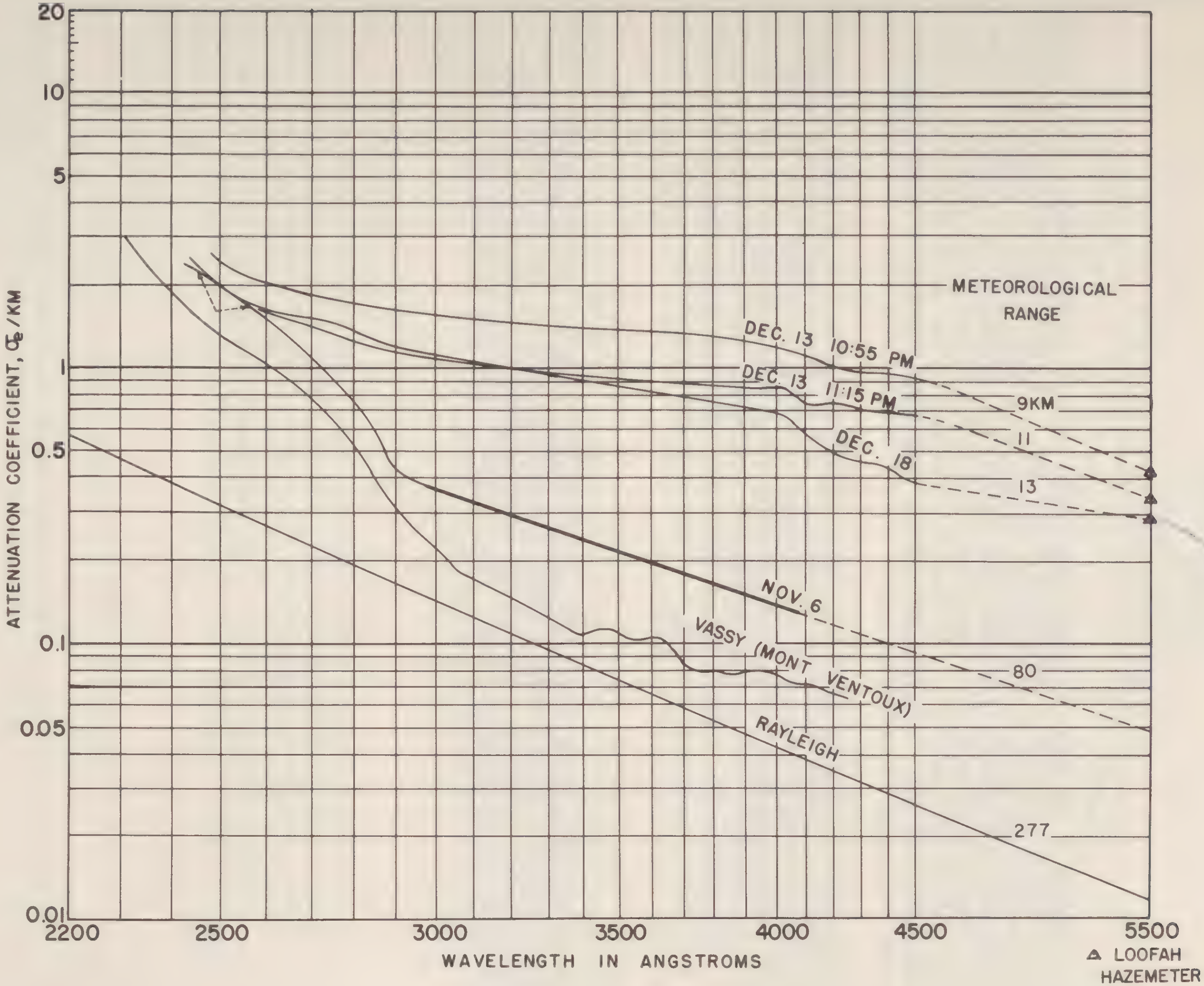


FIGURE 3. Ultraviolet attenuation curves from spectrograms taken during November and December, 1950, in Washington. Included is a curve from data obtained by Vassy for exceptionally clear air.

Report on the Navy Project to Measure Brightness and Illumination at High Altitudes

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At the request of the Chief of Naval Operations and with the sponsorship of the Bureau of Aeronautics and the Bureau of Medicine and Surgery, a project is under way for measuring the illuminations and brightnesses encountered in high altitude flight. The project is under the direction of Commander Norman Lee Barr of the National Naval Medical Center at Bethesda. Sky brightnesses and illuminations will be measured for various parts of the sky at various altitudes. Studies will be made with respect to the sun's azimuth and at various altitudes of the sun. It is planned that the measurements will be made at various locations from the equator to polar regions.

Two aircraft are available for the project: an R4D which will be employed to measure the desired quantities at altitudes below 18,000 feet, and a Banshee jet which will be employed to measure the desired quantities at altitudes ranging from 18,000 to 50,000 feet. Illuminations and brightnesses will be measured both in the upper hemisphere and in the lower hemisphere as well. These measurements will be made with a photoelectric telephotometer and photoelectric illuminometers which will record on a photographic tape oscillograph. In addition, measurements may be made with photographic photometry, so that the precise brightness gradients may be established.

DISCUSSION:

Dr. Hulburt expressed interest in knowing the illumination from the sun received on a horizontal surface at the upper limit of the earth's atmosphere. He stated that this quantity has been inferred by various kinds of measurements, but that the values obtained are not in very good agreement. Dr. Hulburt stated that he hoped that it would be possible for measurements of this quantity to be made.

The Use of Searchlights for Battlefield Illumination

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Searchlights were not used extensively in the battlefield illumination role during World War II, principally because commanders did not realize the advantages of this type of illumination. Searchlights were intended for anti-aircraft purposes, and no time had been given to training army personnel in the use of searchlights for area illumination. Generally the first reaction to searchlights was a howl of protest from commanders because of the lack of training and knowledge. The soldiers felt exposed and felt that they were very good targets. Despite this reaction searchlights were used, and soon after the initial use these same commanders were requesting illumination for their zones. The Infantry made the most extensive use of searchlights in the attack and defense. Almost all organizations that have worked under this type of illumination are strong in its praise.

The Army realized that much better results would probably be obtained if more was known about this new tool. In 1945 a Board of Officers was created at Fort Benning, Georgia, to make a study of Artificial Moonlight as it was so frequently called by the newspapers. Their work resulted in a training circular that outlined methods of employment of searchlights, their capabilities, and limitations. I have a few slides taken from this circular which gives an artist's conception of the effect of this illumination.

SLIDE NO. 1

The first slide shows the use of clouds for reflecting the light toward the ground. The highest level of illumination was obtained by this method. The one requirement that is usually beyond control is that a cloud must be in the proper spot. They never seem to be where you want them. Several schemes have been suggested to provide clouds; the only feasible one was to use an airplane to lay a smoke cloud. In practice this proved to be impracticable with the equipment available to the Army. If some scheme for producing clouds at the right time and place could be worked out, it would be very useful in this application.

SLIDE NO. 2

This slide shows the more common method with no clouds; here the illumination is being produced by forward scatter of light from the searchlight beam. The picture indicates that the greatest illumination is on the side of objects facing the searchlight. Actual measurements made at ERDL indicate that illumination on surfaces facing the searchlig' in the order of five (5) times greater than on surfaces facing away from the searchligl This of course gives considerable advantage to anyone who knows this and uses the illu nation properly.

SLIDE NO. 3

The next slide shows a little better how the searchlight is placed. A searchlight must be out of direct sight of the enemy, or it is very apt to be shot out. You will note that the searchlight in the picture is placed behind a hill. Searchlights placed in this manner are very difficult to locate well enough to direct gun fire against them. The distance from the searchlight to the area to be illuminated varies with the atmospheric conditions and the capabilities of the enemy.

The training circular states that distances up to 15,000 yards are permissable. That

seems like an optimistic figure; however, it might be true. The searchlights are usually located as close to the area to be illuminated as is possible without exposing them to direct enemy gun fire. Battle reports usually mention distance of from 1000 to 10,000 yards. The lights are usually placed about 1000 yards apart along a line parallel to the front.

The amount of illumination produced is not spectacular, but it does greatly assist the fighting units if properly employed. A few instances where it was used during the last war which prove this might be of interest here:

a. The 3rd Infantry Division utilized a platoon of six (6) searchlights during the period of 4-8 February, 1945, in the Neuf-Brisack area of the Colmar pocket. In the opinion of the attacking force, the employment was very successful, and it was highly recommended that the use of searchlights be continued. The Commanding Officers of regiments found the lights gave company, platoon, and squad leaders better control, were able to attain more rigid movement toward objectives, and were able to orient themselves more easily.

b. The British XII Corps on the 15th of July, 1944, in Normandy, used searchlights with good results to provide movement lights in the support of a night attack. The British again used them effectively in September, 1944, in fighting for the Gothic Line in Italy.

c. During a two-week trial period of a searchlight battery in the Ipo Dam section of Luzon, battlefield illumination was credited with being largely responsible for the following:

(1) The halting of a banzai night attack in the perimeter of an infantry company. The Japs left 58 of their dead while making a hasty retreat out of the artificial moonlight.

(2) The saving of a 30-man patrol, which had been cut off and surrounded by Japs. They had enough light to fight their way clear and later direct artillery on the Japs.

(3) It was possible, with the use of the lights, for medical aid men to carry the wounded from the battlefields at night. Previously they had been forced to wait until morning to carry litters back.

(4) The 43rd Infantry Division utilized battlefield illumination extensively on Luzon. Officers of an infantry battalion which had two companies on a ridge most affected by the light believed that the light increased the efficiency of their troops considerably. Even though the light produced is usually about equivalent to half moonlight the above instances indicate that it is very useful. There are many more instances where the light has proved to be of value. I have cited only a few.

I have very briefly covered the history of battlefield illumination as produced by searchlights during World War II. Since the end of the war, very little has been done. There are still many problems to be worked out in connection with its use. The Army Field Forces recognize this and again are working on the problem. There is at the present time an Engineer Searchlight company at Fort Bragg, North Carolina, working out new tactical doctrine for the employment of searchlights on the battlefield. Their first job is to determine just what constitutes a workable unit. The organizations that were used during World War II were originally organized to perform an anti-aircraft role. That type of organization is not well suited for the new role. Searchlight equipment now available is not the best, as it too is anti-aircraft equipment. At the present time it appears as if a more mobile searchlight unit is needed. ERDL is now developing such a unit.

Communication is a problem and, for that reason, there is some talk of making the battlefield illumination companies, Artillery companies, instead of Engineer Companies, as Artillery always have a good communication network for control of their guns. Aiming the searchlight, a part of control, requires a base line from which to start. This calls for accurate survey. There are innumerable problems connected with the seemingly simple job of setting up a group of men and properly equipping them to do the job efficiently.

Very little has been done to determine what jobs can be done with this kind of illumination with varying situations. The number of searchlights, the weather, the terrain, all effect the final results. We hope to be able to get some answers on these and associated problems from work planned in the near future.

We at ERDL believe that none of the problems associated with producing this type of illumination on the battlefield is insurmountable, and that it's popularity will increase as better equipment and training doctrine become available to the Army.

Sources

1. Coast Artillery Journal (Jan-Feb 46) page 33

2. Coast Artillery Journal (Jan-Feb 46) page 20

3. Coast Artillery Journal (Jan-Feb 46) page 22

DISCUSSION:

Dr. Blackwell stated that Mr. John A. Bartelt had asked him to show and discuss a slide representing the Tiffany data, which is applicable to the probable usefulness of artificial moonlight for military operations at night. The figure shown represented a plot of the logarithm of background brightness and the logarithm of size of disk with contrast as the parameter.

Dr. Blackwell pointed out that the graph indicated that large gains in the range at which objects could be detected would be expected by use of artificial moonlight, provided foveal vision was employed. Dr. Blackwell also pointed out that, if parafoveal vision were employed, the curves suggested that there would be very little gain in the range at which objects would be detected with addition of artificial moonlight. For this reason, Dr. Blackwell expressed his belief that the critical question is to discover whether foveal or parafoveal vision is most used for the kind of operations which are of interest to the Army Engineers.

Dr. Blackwell also stated that Mr. Bartelt believed the effect of shadows, which may be cast with searchlight illumination, was a very important one in aiding night visibility. Shadows cannot very well be studied with a two-dimensional projection system, although simulation of this kind might very well be attempted.

FIGURE 3.—*An example of indirect illumination by means of reflection.*

SLIDE NO. 1

FIGURE 4.—*Illumination by diffusion is obtained by laying searchlight beam at low angular elevation.*

SLIDE NO. 2

FIGURE 5.—*Searchlights used for indirect lighting (either by reflection or diffusion) should be protected by a 25-foot defilade and at least the initial 200 yards of the beam should be obscured from enemy observers.*

SLIDE NO. 3

Proposed Study of Visual Thresholds under Artificial Moonlight

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The purpose of the proposed study is to duplicate, under carefully controlled laboratory conditions, the visual target situations met with in the field where artificial moonlight is utilized for illumination.

The field situation consists of a target against a background. There are three possible sources of illumination to the target and its background, these being in the order of their probability or significance (1) vertical scatter from the searchlight beam which provides the artificial moonlight, (2) incidental phasic or continuous light from moon or stars or sky glow of artificial or natural origin, and (3) direct horizontal illumination from the searchlight beam mentioned above. Illumination from the first source would presumably illuminate the target and its background equally, whereas the second source would illuminate the background equally or unequally depending on the distribution of the sky glow. The third source would provide considerable contrast because of the creation of shadow areas behind the target. It would be expected that the first and third sources would reduce shadow contrast but, at the same time, would be additive for total illumination of the target whenever all horizontal c omponents of the searchlight beam did not clear the target object entirely. In any event identification of the target object against its background would depend upon the brightness ratio between the two and, if the total illumination is increased, the brightness ratio required for detection is reduced.

The method of approach under consideration involves duplicating the field conditions in the laboratory where transmission aberrancies may be minimized and photometric accuracies may be maximized. The work will be carried out with a background illumination varying from no light to 1×10^{-4} foot candles. The superimposed simulated artificial moonlight will vary from 1×10^{-2} to 1×10^{-5} foot candles. Determinations will be made of the brightness ratios required for probability of detection of simulated target objects.

There are two methods of approach to be considered in the proposed laboratory procedures. The first of these methods involves the projection of two-dimensional realistic target images upon a screen. The target images will originate from projection slides prepared from photographs made of representative target objects (soldier in different positions, troops, tanks, trucks, etc.). The photographs would be made under conditions of high-level illumination and would be in a series such that distances from the observer varying from 500 yards to six feet would be simulated depending upon the relative size of the particular target chosen. The backgrounds of the slides would be filled in so that the projected light would come through only the figure of the target. The intensity of the projection light would be varied to produce the ranges of target illumination described above.

The background upon which the image will be projected will consist of a screen of opal glass illuminated from behind uniformly and recessed so as to maintain a uniform background by preventing possibly distracting lateral scatter. The illumination from the rear will consist of a projected light varying in intensity from no light to 1×10^{-4} foot candles. This projected light may be neutral or in addition or by substitution may be through slides made from photographs of variable and typical terrains proportioned to the size of the target image in use. In any instance the projected light will be in the foot candle range just indicated.

The second method of approach is to use three-dimensional realistic target models. The reason for this procedure is obviously to determine the effects of stereoscopic vision and the shadow production behind the target upon the probability of detection. It is proposed to have models of the target objects in varying sizes so as to simulate the above mentioned distances from the observer and to construct the models from the same sources from which the projection slides were made. These models would be arranged so that they could be ejected up through slots onto a stage in the manner of disappearing targets used in shooting galleries. The type of stage upon which the models would appear may be one or many of several possibilities. One may use a flat neutral stage or a rotating stage, segments of which would have various simulated types of terrains. By substitution or in addition, it may prove feasible to use the neutral screen or the projected slides of various terrains behind the screen.

The method of illumination of the target model and background would be determined by the nature of the background used. If a flat neutral stage or one containing simulated terrains is to be used, then one possibility would seem to be a source of light overhead to the stage background, shielded from the observers, and in front of the target to prevent shadow destruction. Another possibility is the use of a horizontally cast beam originating in front of and cast above the target and its background in exact imitation of artificial moonlight in the field. However, a possible disadvantage here would be the absence of very much vertical scatter from the beam in the laboratory situation. Finally, direct projection of a light beam onto the target must be considered as a means of simulating artificial moonlight. Each method will be attempted through the ranges of illumination mentioned earlier in an effort to find the most effective light source for imitation of artificial moonlight. In addition, background illumination would be provided by general overhead illumination above the target and stage and would vary from no light to 1×10^{-4} foot candles. It may further prove feasible to display the target models in front of the screen used for the two-dimensional images, and this will be attempted either using the neutral screen with transillumination or the slides of typical terrains may be projected by light of variable intensities through the background ranges. Reflectance factors must be considered in using the three-dimensional models, and these will be maintained at a minimum insofar as it is consistent with field conditions.

Twenty subjects whose participation for the duration of the project can be guaranteed will be used. It is intended that dark adaptation rates, visual acuity, perimetric, and refractive measurements shall be made on each subject. The subjects will be sophisticated with respect to the target images or models, and these will be presented both at random, to rule out recognition by chance, and in a sequence unknown to the subjects. It is intended to present the visual images and targets at different points in the visual fields with and without fixation points. The use of fixation points will enable us to measure the effectiveness of parafoveal vision as against foveal vision.

The data derived from these experiments will be in the form of curves of probability of correct identification of target objects at given brightness ratios and given overall illumination intensities.

It is intended that confirmation of any data obtained in the laboratory will be attempted in the field. In the latter instance, the effect of variations in atmospheric transmission will have to be considered, and work on this may be carried out on a laboratory scale at a later time. Also, the use of night glasses will be considered as a measure of correction for nocturnal myopia.

DISCUSSION:

Dr. Kincaid questioned Dr. Bach's dichotomy between horizontal and vertical illumination. Dr. Kincaid pointed out that illumination of targets produced by artificial moonlight will consist of various amounts of light scattered at every angle from horizontal to vertical, and that there is no dichotomy between these two kinds of illumination.

Dr. Paul agreed with Dr. Kincaid that illumination on targets will be from all directions. He stated that the ratio of front to back scattering is about two to one.

Dr. Duntley stated that, in his opinion, if one is going to simulate the three-dimensional case, the simulation must be extremely good. The geometry of lighting will be very important. The distribution of light striking a target by scattering from the searchlight beam will depend upon the focusing of the beams of the projector and, of course, it will depend upon atmospheric conditions. For example, in addition to dependence upon the overall atmospheric attenuation, the pattern of illumination will depend upon the size of particles in the air. For this reason, Dr. Duntley expressed his opinion that, if Dr. Bach plans to go to the trouble to set up three-dimensional models on a stage, he will need to spend considerable time in studying the probable geometry of lighting which will be encountered in the field.

Dr. Duntley asked Dr. Bach if he would discuss the psychophysical procedure which he plans to utilize. Dr. Duntley asked whether it would require detection or recognition.

Dr. Bach replied that he could not describe a psychophysical procedure in detail, because the technique has not yet been worked out. Dr. Bach stated that the subjects will be required to correctly identify the objects seen. Initially at least, moving objects will not be used, since the perception of moving objects is believed to be an additional problem. Dr. Bach also expressed his awareness that the geometry of lighting is an important problem, since the contrast and shadowing will depend upon the exact character of the scattering from the beam.

Dr. Duntley asked Dr. Bach if he planned to measure thresholds of detection of presence in a two-dimensional object in order to relate the result obtained to the older work on detection thresholds.

Dr. Bach replied that it would not be possible to relate the thresholds which he is interested in to the earlier work, because the earlier work was done with two-dimensional objects, whereas the problem in which the Army is interested involves objects with definite three-dimensional characteristics.

Lt. Cdr. Farnsworth emphasized the parallelism between the present problem and the problems encountered during the last war involving submarine detection. Cdr. Farnsworth stated that, in studying submarine detection, different levels of response were studied, such as detection, identification, etc.

Cdr. Farnsworth expressed his opinion that the most important problem in the use of the artificial moonlight is to train men in the field to take advantage of the illumination. Army personnel could be trained to take advantage of recognition of shadows and the use of off-center vision. Cdr. Farnsworth stated that he believed the level of illumination present, even with artificial moonlight, is still in the range in which off-center vision should be used. To prove this, Cdr. Farnsworth commented that no one had been able to detect the color of the lining of Dr. Rand's coat which was a bright scarlet color. Failure to detect this saturated color suggests that the level of illumination was below

the terminal cone threshold and, therefore, off-center vision would have been advantageous. Since the illumination will vary from night to night depending upon atmospheric conditions, this suggests that one of the most difficult things the men must be trained to do is to ascertain the degree of off-center vision which should be employed on a given night.

Dr. Crozier expressed the opinion that it would be quite difficult to go from detection thresholds to thresholds of recognition. Dr. Crozier reported recent results obtained with foveal vision, with small squares as stimuli. It was found that, above the detection threshold, there was a range in which partial recognition of form was possible. For example, a portion of the square would be seen clearly, whereas the rest might be completely unrecognized. Dr. Crozier stated his belief that the frequency of recognition curve is considerably flatter than the frequency of detection curve.

Dr. Dimmick stated his agreement with the opinion that it will be essential for Dr. Bach to study the geometry of lighting so as to know the patterns of illumination to be expected under various atmospheric conditions; however, Dr. Dimmick emphasized that the eye will be unable to detect differences in depth at low illuminations such as that encountered in the night problem, and that, therefore, it should be perfectly safe to stimulate three-dimensional shadowing with two-dimensional targets.

Dr. Dimmick asked Dr. Bach what he planned to use as his measure of identification. Dr. Dimmick pointed out that identification measures are relatively simple when one is using formalized objects, such as circles and squares, but that the problem is not so simple when one is dealing with real objects, such as soldiers and tanks.

Dr. Bach replied that he did not have any predetermined notions as to what the measure of identification would be, but that he was certain that he would be able to work out a suitable measure once the research got under way.

Dr. Scobee stated that he would like to emphasize the point made by Lt. Cdr. Farnsworth. Dr. Scobee stated that during the last war it was necessary to teach men to recognize targets, and it was found that targets should be made extremely realistic, and that training was capable of resulting in important improvements. Dr. Scobee suggested that Dr. Bach might be interested in examining the gallery of targets which was set up at Pensacola or the Evelyn night vision training device.

Dr. Blackwell emphasized the point he had made on Friday that the extent of gain to be expected with the use of artificial moonlight depends upon whether foveal or parafoveal vision is to be used. With foveal vision the gain due to artificial moonlight might be very considerable, whereas with peripheral vision the gain might be expected to be very small indeed.

Dr. Blackwell also stated his belief that, because of the virtual complete absence of depth perception at low levels of illumination, it should be possible to simulate the three-dimensional objects satisfactorily in two-dimensions. Because of the obvious complications due to the geometry of lighting, Dr. Blackwell proposed that Dr. Bach start with two-dimensional objects in the laboratory and then proceed to the field, rather than employing the intermediary condition of three-dimensional targets in the laboratory.

Dr. Blackwell stated some concern with reliance upon the intuitive feeling of comfort people get at night as an index of the extent of advantage to be gained by artificial moonlight. Dr. Blackwell pointed out that, in walking around in the dark, most of us probably use foveal vision rather than parafoveal vision, and the curves demonstrated on Friday indicate that there will be considerable gain under these conditions. However, presumably

military personnel will be trained to employ parafoveal vision for critical seeing at night, and it is entirely possible that they will experience very little gain as a result of artificial moonlight. For this reason, Dr. Blackwell stated his belief that the advantage of artificial moonlight be carefully studied under as real conditions as possible.

Mr. Middleton stated that he was very much impressed with the directional aspect of the problem during the night demonstration. The searchlight beam is, of course, of high brightness compared with everything else in the field, and one of the advantages of the technique may be the fact that the enemy has to look for objects in the vicinity of the bright searchlight beam, whereas friendly troups do not have to look for objects in the neighborhood of the bright searchlight beam. The brightness of the searchlight, and the relation between this brightness and the illumination cast by the searchlight, will depend upon complex aspects of the atmosphere and, for this reason, Mr. Middleton expressed his belief that it would not be possible to simulate the use of artificial moonlight adequately in the laboratory.

Mr. Pulling stated his opinion that, in practice, detection would be involved rather than recognition, since in the tactical employment of artificial moonlight, friendly troups would fire at anything which was detected, and would not delay firing until recognition was established.

Mr. Robert Brown stated that he would like to see some provisions made for confusion. For example, in night operations, it must be difficult for the troups to avoid picking out a hill and calling it a tank. The hill and tank look alike, of course, so long as the tank is not moving.

Mr. Brown also pointed out that, since the targets are moving, it will be necessary to obtain some kind of cumulative probability of the targets being detected at any time during a given movement pattern.

Dr. Duntley suggested that Dr. Bach should arrange to get a very fast camera with very fast film in order to take photometric photographs in the field during employment of artificial moonlight. By sensitometric techniques it would be possible to determine the distribution of brightness on various targets. Such data would be extremely useful in setting up two-dimensional targets to simulate conditions encountered in the tactical employment of artificial moonlight.

Survey of Available Media for Detection Goggles

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I

During two wars a considerable number of military inventions and applications of spectral filters were made by present and past members of this Committee. Since the same problems are again arising and similar needs will appear in the future it seems well to assemble available data so that the exploratory work already accomplished will not have to be repeated and so that some of the techniques will be easily available to members of the Committee. It is necessary to point out that the word "available" in the title does not mean that all of these media can be ordered over the counter; in some cases no supplies are available and sometimes it means only that the "know-how" for producing them are available.

Detection goggles may be divided into two very different classes according to usage. (1) Used for discovery they are designed to promote the detection of objects too small to be otherwise seen. (2) Used for identification they are designed to permit the detection of certain visual qualities which will identify objects in clear view. In either case the function of a goggle is to increase the differences between colored areas in the visual field in hue, value or chroma, or in two or three of these color dimensions. The listing in this report treats only of known examples of direct vision detection filters, unaided by mechanical or electronic devices.

In problems of discovery it may be expected that the object will first appear below threshold or at threshold. The purpose of the filter is to raise this subliminal object to, or well above, threshold (as in the search for a life raft). It can be assumed in such a case that by the time the thing is seen with certainty there is no longer any need for the goggles. When used for identification, a filter functions as a kind of extremely simple spectroscope for one spectral region, at least in the sense that it enables the observer to make a specific spectral differentiation. In these cases it is necessary that the objects to be examined subtend more than a few degrees of visual angle.

II

A few general statements can be given regarding the selection of colors and filters in both types of detection problems. Obviously, compromise and selection is necessary since no filter can satisfy all of the desirable features in any specific problem.

1. Maximum differentiation may be expected in the red-white-green directions. The chromatic effects of yellow and blue diminish or disappear except as they contribute to luminance.

2. An approximate neutral balance should be maintained in the selection of filters. If a filter causes a yellow target to appear red, the noticeability of the target is diminished rather than increased if the background also turns red. (An example of balanced dichromatic transmission is Eastman 1635 1/2.)

3. The effect of the filter should be to increase, or at least maintain, the brightness contrast of the target and background (as with tracer fire and sky). If the target is normally lighter than the background, visibility may be diminished if the effect of the filter is to decrease equalize or reverse the brightness difference. As a general rule in detection a small brightness difference is equal to a large chromatic difference. (MacAdam, 1944)

4. If choice exists, first thought should be given to the type of filter which transmits most highly in the region of maximum luminosity. A dense filter may achieve chromatic contrast at too much expense of light loss even though the contrast ratio is maintained.

5. The effect of the filter should be to increase contrast not only with the background but with non-significant items in the background. Thus the problem with life jacket yellow is not only to make the yellow conspicuously different from the sea, but also conspicuously different from white caps.

6. Nearly complete adaptation to the brightness level produced by the filter is required. Peripheral light must be shielded and account taken of time for adaptation if it is necessary.

7. Detection is a compound function of chromatic and brightness acuity. Therefore no optical characteristics of the detection goggle should diminish acuity. The optical qualities should be of the best, the exposed surfaces should be easily cleanable, and the media should not be diffusing. Wratten neutral gelatins should be avoided; neutral glass or Bausch and Lomb metallic coated glass is acceptable.

III

The objects which occur in discovery problems almost always appear first as targets of a few minutes of visual angle - mere flecks of color. Hence, the color relationships commonly derived from the 1931 I.C.I. Standard Observer and Coordinate System (designed for colors subtending a few degrees of visual angle) are inadequate and misleading. Koenig's observation (1894) that the eye is yellow-blue blind for color at small subtense has been confirmed by Farnsworth and Reed (1944), Willmer (1944), Willmer and Wright (1945), Hartridge (1947), and Middleton (1949). Adequate conversion of the I.C.I. data to fit small subtense relations depend upon many factors which have been inadequately studied - such as quality and quantity of illumination, contrast, background, observational methods - but a first approximation was presented in the New London Color Vision Report No. 7 by which a rectilinear conversion can be made of the 1931 Co-ordinate System to express the psychophysical relations of colors at several subtenses. A projective transformation of the I.C.I. Diagram empirically derived from the experimental data is shown in Figure 1, upon which equally discriminable colors at about 1 minute of visual angle will be approximately equally spaced. This is a rough approximation but very useful.

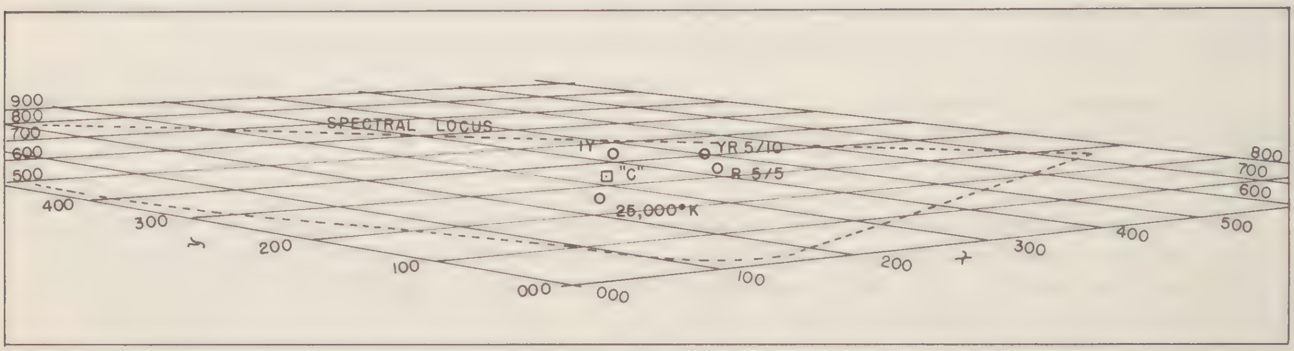

Fig. 1
Projective Transformation of I.C.I. Diagram
to approximate uniform chromaticity spacing
at 1 minute of visual angle

Certain of the chromatic limitations applying to detection colors and applying to filters for their enhancement can be deduced from Figure 1. It is apparent that in general principal dependence must be placed on reds and greens. No matter how vivid a yellow may appear in the hand, or at moderate distances, reference to the chart shows that it has minimum contrast with white, gray or blue at detection distances. It also shows that no possible increase in the strength of the yellow could be as effective as a slight change in hue toward green or orange. A yellow used for life rafts will be used for demonstration. The colors approximate Munsell 1 Y 7/8. Plotted on Figure 1 the position is seen to be close to Illuminant C (white caps) and indeed not far from 25,000° K (probably maximum for blue water).

It is also apparent that a filter intended to enhance visibility of this color at threshold should be chosen so as to convert the yellow to an orange or green hue. There are three reasons why the red direction should be chosen. First, inspection of the spectral reflectance of the yellow shows that there is relatively less green than red reflected from the material so that a green (red absorbing) filter would produce the greater loss of brightness. Second, dichroic dyes which balance on neutral and which have high red transmission are more easily devised than are their complements. Third, since the yellow already appears more reddish, rather than greenish, as compared to white, some of the absorption of a green filter would be wasted in moving the yellow back past white toward the green.

Another phenomena is illustrated in Figure 1. A brilliant orange (YR 5/10) is plotted against a dull red of half the chroma (R 5/5). It is apparent that chroma is no test of visibility at small subtense for the points are at about equal distances from Illuminant C. Tests have shown them to be of about equal detection value. Similarly, it can be shown that because a filter appears to make an object more vivid at a degree or two of visual angle is no guarantee that the effect will hold at detection range.

IV

The following list of detection problems is made up according to common applications with notes added on sources of materials, an example or two of usage which has been made in the past, types of filters, etc.

1. To distinguish a true neutral pigment or filter from a dichromatic pigment or filter. . Example: testing sunglass lenses for neutrality; operation of signalling systems which appear white to the observer without key filters. Filters: Eastman, Experimental #683; Whiting's Filterlites, A, B, C and D.

2. For visual determination of specific regions of transmission. Example: inspection goggle for checking correspondence to specification of red filters for dark adaptation. MRL Report No. 170, 1951. Filter: Wratten 44A.

3. To enhance or exhibit polarization differences by color. Usage: No known application but has been suggested as a recognition device. Filter: Polaroid Corporation two component or double dichroic red-green and red-bluegreen filters.

4. For separation of dichromatic gray paints. Example: the invisible difference grays designed by Captain Charles Bittinger for the submarine service to permit recognition from the air. Filters: Eastman Experimental #2387-2389.

5. The enhancement of pyrotechnics against light backgrounds. Example: Following tracer bullets. Filters: red, XR18M-Polaroid; Army green MG30; Canadian, purple; red-bluegreen dichromatic. Bunker and Solandt (Proceedings, 8th Meeting, 1944) and Peckham (Conf. Supp., 11th Meeting, 1945).

6. Chlorophyl identification. Usage: Camouflage detection; to distinguish between foliage and green paint, between foliage and green paint which simulates chlorophyl reflection, between live and dead foliage. Developed by Drs. Jones and Duntley, Captain Bittinger: Filters: red-bluegreen dichromatic: Eastman Nos. 97, 97A, 97B, 1635, 1635 1/2; Ft. Belvoir dichroic A and B.

7. Air-sea rescue. Usage: to promote the discovery of yellow life rafts and dyes against backgrounds of blue-white water and white caps. Filters: Wrattens No. 16 and 23A; and red-green dichromatic, similar to above.

8. Ground-to-air signalling. Usage: to increase visibility of fluorescent red tarpaulin, and red, orange and yellow signal strips. Filters: red-bluegreen dichromatic, as above, but selected as necessary to complement particular colors.

9. To increase signal strength in instrument reading. Usage: Radar and oscilloscopes. Filters: orange, selected according to spectral characteristics of fluorescence; also, see O. H. Straus, these Minutes.

V

The problem of recognition devices is not completed with the selection of the filter which will, under certain conditions, increase chances of discovery or increase spectral differences. The type of media in which the filter is available, its stability, and the mounting of the filter may determine whether or not it will be useful. Highly dichromatic filters are most eaily made up in gelatin which must be mounted between glass. The result may be an optical item which is too unwieldly or troublesome for use when it is most needed. Furthermore, while a recognition filter may promote discovery under a certain set of lighting and background conditions, it may equally well retard recognition under another combination of conditions. It is therefore necessary that the filter be easily removable from the field of view and as easily replaced. The following devices are a few of the common designs which have been made for the convenient use of filters for binoculars. They are given here as suggestions for future applications.

1. Binoculars. A snap-in-and-out glass cell mounted parallel to the plane of the lenses. It is usually necessary to incorporate an eye cup in the design in order to exclude peripheral light and secure complete adaptation.

2. Goggles. Colored glass or filters cemented between glass which are inserted in common types of industrial goggle frames.

3. Flipper. A hinged flipper which permits a holder or plastic filter to be flipped down in front of the eyes or up to the forehead. Same, attached to visor of cap. Same, attached to head band or helmet.

4. "Bifocals" made up with a neutral filter in upper part of the lens and the test filter in the lower third so that the head can be raised to bring the object into the field of view of the detection filter. Dr. Duntley proposed this arrangement as a means of incorporating dichromatic search filters in sunglasses (for chorophyl detection, air-sea rescue).

5. Browrests. When suitable transmissions can be developed in flexible plastics the plastics can be mounted in browrest goggles. Browrests are so light that they can be removed or replaced easily and they have the advantage of being cheap and therefore expendable when they become dirty or scratched. The Pioneer Scientific Corporation has been working closely in conjunction with our Laboratory in the production of a frame design which will correct the deficiencies of the previous types. The Plastics Division of the Monsanto Chemical Company is attempting to duplicate some of the more useful dichromatic dyes in plastic for incorporation in the frames.

DISCUSSION:

Dr. Duntley rose to disclaim credit for the development of the camouflage detection filters. He stated that the series 97 filters was developed by L. A. Jones and Captain Charles Billinger in World War I for detection of green paint against grass. The filters were declassified after World War I. In World War II, Dr. Duntley recomputed the filter characteristics to take account of the spectral change produced by haze.

Dr. Grether stated that, in his experience, excessive scratching of plastic goggles means that they must be thrown away soon or else there will be a loss in visual acuity which more than compensates for the gain due to contrast enhancement.

Cdr. Farnsworth stated that he was well aware of the scratching problem. He suggested that the solution to the problem of plastic goggles must be at one or the other extreme, i.e., either very high-grade goggles should be used which fit various face types or else completely cheap goggles should be developed which can be thrown away as soon as there is damage to the surface. Cdr. Farnsworth suggested that in Europe there had been attempts made to supply six or seven different types of glasses to fit various types of faces, but that this type of goggle is very expensive. The goggles Cdr. Farnsworth recommends are extremely cheap, so that there will be no question but that they can be discarded when they are in any way damaged.

On Visual Photosensitization and Oxygen

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Abstract

1. Seeing-frequency $\Psi(S)$ data at the dark-adapted fovea have shown that, across the spectrum, the slope of the log-Gaussian curve is a periodic function of λ. In the retinal periphery nothing of this sort is found. Tentative identification was suggested for the peaks in $\sigma_{\log \Delta I_0}$ vs. λ as representing energy absorption by components of the cytochrome respiratory enzyme system: cytochrome-c reductase, reduced cytochromes-c and -a, and oxidized cytochrome-c (J. Gen. Physiol. 1950, 34, 87). There is implicit here the assumption that there is a connection between $\sigma_{\log \Delta I_0}$ and the 'size' of the available population of excitable elements determining $\Psi(S)$. This is not related in any simple way to image size, nor should it be expected otherwise. There is entire concordance with the data of $\Psi(S)$ as function of light-adaptation, with λ fixed.

2. The mechanism conceived to be operative, on this basis, is photosensitization (photocatalysis). If this notion is at all correct, two general expectations must be entertained: (i) Direct evidence should demonstrate that photosensitization does occur (homochromatically, and heterochromatically); this has been referred to in: Proc. Vision Comm., Ottawa Meeting; the spectral characteristics of this process are now being worked out. (ii) The specific suggestion that in the zone $\lambda\lambda$ 550-605 the senitizing absorbers are reduced cytochromes entrains the possibility (Proc. Vision Comm., Ottawa Meeting, May, 1950) that in this λ-zone, and not outside it, the efficiency of threshold excitation at the dark-adapted fovea should not be improved by increasing the partial pressure of O_2 inspired, and might even be decreased; and conversely for the effect of reducing the O_2-intake.

3. This has been tested systematically, and with confirmation. The expected effects must be complex, since it is demonstrable that image size, for example, and binocular regard, alter the magnitudes of the O_2-effect. It is shown that the increase of excitability under "100 per cent" O_2 is greater for binocular regard than for uniocular. The p.p. of O_2 inspired has two kinds of effects - one, peripherally, at the eye; the other effect is central.

4. As a contribution to the analysis of this situation there was compared, with λ 551.5 and a square field subtending 0.5° at the fovea, the relations between $\Psi(S)$ and exposure-time (25 exposure-times, 0.12 sec. - 0.0004 sec.) when (a) breathing air and (b) breathing "100 per cent." O_2 (plus CO_2 and water vapor), at sea level total pressure. The I, t contour is actually complex, and gives no real basis for the traditional interpretation in terms of the "reciprocity rule"; it consists of a series of cusps, time specific, denoting the intervention of minor but significant features in the dynamics of the photosensitization process. It has been noted that the occurrence of these specific cusps is quite apparent in all the data supplied by others in the past 45 years, although never noticed (Proc. Af-NRC Vision Comm., Washington Meeting, 5 March, 1949).

5. The data show that, for these conditions, over the exposure-time span indicated, the inflection-abscissa of $\Psi(S)$ (log ΔI_0 for 50 per cent frequency of recognition) is either not changed by inspiration of "100 per cent." O_2, or is sharply elevated. The details of

structure in the contours, as related to the complex form under high 0_2, reinforce the analytical reality of the "cusped" shape.

6. The other usable parameter of $\psi(\underline{S})$, namely $\sigma_{\log \Delta \underline{I}_o}$, shows periodic changes as $\underline{t}_{\text{exp.}}$ is altered. These changes are specifically correlated with the cusped points in the $\Delta \underline{I}_o$ vs. $\underline{t}_{\text{exp.}}$ curves. As "accident," this is impossible. The interpretation in relation to the "size of available population of excitable units" will be dealt with in the full publication.

7. For real consideration of the "quanta for vision" problem these observations must be pushed to shorter exposure-times, and other peak wavelengths must be used in order to investigate the systematic properties of the energy minima for $\psi(\underline{S})$. As they stand, the present data are completely in accord with expectations based on the notion of specific photosensitization (at the fovea) by way of materials of the kinds deduced from the peculiar properties of $\psi(\underline{S})$ in relation to λ.

Effect of Retinal Illumination on Stereoscopic Perception of Space

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You are all familiar I am sure with the works of Ames who was first to describe the alteration of visual space due to aniseikonia, i.e., unequal imagery in the two eyes. By interposition of a size-lens in front of one eye aniseikonia of the type described by Ames can be artificially induced. Phenomenally, the effect consists in a swing of the visual field about a common pivot point as illustrated in Figure 1.

In this paper an attempt is made to describe and analyze a second type of aniseikonia which is related to physiological properties of the retina as the receptor organ of light stimuli. Changes in size of retinal and perceptual images by altering retinal illumination take place without noticeable distortion of the images, irrespective to their shape and location on the retina. Because of this fact aniseikonia of Type II is accompanied by a disturbance of space perception which differs decisively from that experienced in aniseikonia of Type I (Ames).

Figure 2 illustrates the effect of aniseikonia of Type II. The real pattern may also consist of two square targets (solid arrows) lying symmetrically in a fronto-parallel plane. The retinal illumination of the right eye may be reduced by interposing a neutral density filter. The broken arrows demonstrate the special characteristics of the distortion of perceptual space which is now produced. The targets appear rotated, individually, about two separate pivot points located in the two targets. This type of spatial distortion associated with aniseikonia of Type II may be called "Venetian Blind Effect." Since the dark interspace between the adjacent boundaries S and P of the white targets is mostly seen as slanting obliquely between the points of S' and P' after the introduction of the neutral density filter, one may also speak of it as a "Saw Tooth Effect."

Physiological Background

If an inherently sharp boundary between two areas of different brightness in the visual field is imaged on the retina, a variety of factors prevent the brightness pattern on the retina from being rectangular in shape. Owing to diffraction, chromatic aberration, refractive differences, scattering of light and other physiological movements of the eyes, the "light hill" on the retina can be expected to taper off in the manner illustrated in Figure 3, where the case of a rectangular white pattern before a dark background has been chosen. In the same figure, the lower horizontal line represents the surface of the retina. Its intersection points with the light hill determine the objective size $\underline{s}$ of the retinal image. The horizontal line $\underline{t}$ indicates the threshold level of the retina; brightnesses reaching or surpassing this level cause the receptors of the retina to respond and to transmit the stimulation to the corresponding cortical center of vision. Because of the sinusoidal slopes of the light hill the threshold level $\underline{t}$ cuts a smaller cross section $\underline{r}$ out of the light hill. $\underline{r}$ may be called the receptive size of the retinal image. As illustrated by the dash-dot lines, only the receptive size $\underline{r}$ can be transmitted to the terminal zone in the visual center. Since it is believed that a threshold level exists also in the terminal zone, the size of the image

which is finally perceived will be further diminished. Accordingly, the objective size s of the original image is reduced to the perceptive size p. A second set of light hills in broken tracings show the effect of, for instance, a neutral density filter of 50 percent transmissivity which cuts the ordinates of the original light hills in half. As can readily be seen from the figure, the perceptive size of the images is altered, although the objective size of the retinal image remains constant. Therefore, we can conclusively say: aniseikonia of Type II is produced by a change of the perceptive image size.

A similar change of the perceptive image size p can be expected, if the slope of the light hill is altered, the threshold levels are lowered or raised, and if the conductivity of the visual pathways is impaired. All these factors will similarly produce aniseikonia of Type II. These considerations permit us to list a variety of factors which can be expected to produce aniseikonia of Type II. They are: monocular changes in retinal illumination by introducing neutral density filters, rotating sectors, and color filters; anisocoria, anisometropia, differences in transmissivity and pupillary shape in the two eyes, unequal preadaptation to light, unequal sensitivity to light and pathological changes of the visual pathways and the visual centers.

A further important difference existing between the imagery related to aniseikonia of Type I and Type II may be discussed here. In aniseikonia of Type I, a contiguous bright and dark pattern, for instance, suffers an over-all magnification of diminution, whereas in aniseikonia of Type II the dark areas grow at the expense of the bright ones as a consequence of a shift of the boundaries in the perceptive image.

Method and Analysis

Aniseikonia of Type II can be measured in the following manner: two square targets are presented in symmetrical convergence to an observer in a completely dark room at a fixed distance (3 m. in our experiments) (Figure 4). The observer attempts to eliminate the apparent rotation of the two targets caused by diminution of the retinal illumination in one eye. For this purpose he tries to readjust the real targets into the apparent fronto-parallel plane. This is done by manipulating a pulley which simultaneously rotates the targets about two vertical axes. The axes lie in the plane of the individual squares and pass through their midpoint. The angle of rotation, ρ , which must be applied in order to readjust the targets into the fronto-parrallel plane, is a measure of the effect produced by aniseikonia of Type II (Figure 5). The accuracy of the method is limited by the observer's threshold of space discrimination. The data obtained experimentally for the angle ρ can be converted into terms of angular disparities, δ , by applying simple analytical geometry. The angular disparity δ is defined as the angle that is related to the shift of the original boundary P toward the apparent position P' obtained after introducing the light diminishing device in front of one eye. The relationship between ρ and δ is given in equations (1), (2), and (3).

$$\delta = \alpha - \alpha' \qquad (1)$$

$$\delta_R = [2s/b] \cdot [a/2b] \cdot \sin\rho = k \cdot \sin\rho \qquad (2)$$

$$\delta_L = -[2s/b] \cdot [a/2b] \cdot \sin\rho = -k \cdot \sin\rho \qquad (3)$$

whereby s is half the width of the target, b the observation distance, and a the interpupillary distance.

Equations (2) and (3) cover the measurements in the experiments described with sufficient accuracy within the range $0 \leqslant \rho \leqslant 60^{\circ}$.

A detailed description of the mathematical deduction is given in a report in publication by the School of Aviation Medicine, Randolph Field, Texas, (Project Number 21-31-011, Report Number 1). From the equations given above the conclusions can be made that the apparent angular disparity of contours associated with aniseikonia of Type II is proportional (1) to the visual angle at which the target is seen (2s/b), (2) to the angle of convergence (a/2b), and (3) to the sine of the position angle ρ of the real patterns, when the apparent patterns are perceived as lying in the apparent fronto-parallel plane.

Measurements

For the purpose of measurements, aniseikonia of Type II can be introduced by monocular application of:

1. Neutral density filters or rotating sectors.
2. Pupillary diaphragms.
3. Spherical and cylindrical lenses.
4. Bleaching of the retina.

Figure 6 shows a scatter graph of the results after introducing density filters. The ordinate gives the values of the corrective angle of rotation, ρ , in degrees of arc, the abscissa the density of the filters applied. Figure 7 represents the relationship between the apparent angular disparity in seconds of arc and the density of the filters. Figures 8 and 9 show the same relationships where the arithmetic means and the standard deviations of the measuring results are plotted. From these results the following conclusions can be drawn:

1. Differences in the retinal illumination between the two eyes produce the "venetian blind" effect characteristic of aniseikonia of Type II.
2. The effect is essentially symmetrical in the two eyes.
3. The spatial distortion associated with aniseikonia of Type II as dependent on differences in retinal illumination exhibits the general trend of a saturation curve. The relationship is approximately linear up to filter densities of 1.25, while saturation is reached at filter densities of 2.5 to 3.0.

The following discussion is confined to that part of the graphs in Figures 6 and 8 which can be approximated by a straight line, i.e., up to densities of 1.25 either in front of the right or of the left eye. Figure 10 shows straight line approximations of the results of ten observers. These approximations were obtained by the use of the method of the least squares. It may be noted that the observer M.H. is distinguished by having an amblyopia of the right eye. As can be seen, the straight lines of the majority of the observers do not pass through the origin of the system of coordinates. This phenomenon shows that only few observers are without a certain basic aniseikonia effect when both eyes are naked. The segment ρ is a measure of the basic effect, whereas the segment d_o is the density of the filter required to eliminate this basic effect. At the same time d_o is a measure of the differences of the perceptive images in the two eyes which exists in the individual observer. This inherent difference can be caused by one or several of the factors listed above which can be responsible for aniseikonia of Type II.

Expressing the straight segment of the averaged results analytically we obtain:

$$\rho = [\rho_o/d_o]\, d + \rho_o; \quad \rho - \rho_o = -|[\rho_o/d_o]| \cdot \log \tau \qquad (4)$$

whereby τ is the transmissivity of the neutral density filter defined by the relation $d = -\log \tau$. Since ρ_o and d_o are constants for any particular observer, it can be concluded from (4) that the degree of apparent rotation in addition to the basic aniseikonic effect is proportional to the negative logarithm of the transmissivity of the light diminishing device used in front of one eye. Because the quantity is always < 1, equation (3) expresses the fact that the apparent rotation associated with aniseikonia of Type II increases with decreasing illumination of the retina. This law holds as long as the ratio of the retinal impulse in the two eyes stays within the range of 1 and 32 ($d = 0$ and $d = 1.5$) while the conditions of photopic vision are maintained.

The studies related to the effects of different retinal illumination raised the question as to how a variation of the basic level of brightness of the targets would influence the results. Figure 11 shows the results obtained from two observers. These measurements were made with six and seven different brightness levels, ranging between 0.0125 and 35.0 millilamberts, respectively. As can be seen from the graph, the apparent angle of rotation as a function of the monocularly applied filters does not vary significantly, if brightnesses ranging between 0.01 and 35 millilamberts are presented to the observer. In general, the data obtained suggest that the scattering of the trends beyond a density of 1.3 increases as the limit of pure scotopic vision is approached.

The effects of aniseikonia of Type II caused by interposition of pupillary diaphragms in front of the eyes are shown in Figure 12. The abscissa are given in differences of pin-hole diameters between the two eyes in mm. Ordinates are angular disparities in seconds of arc.

Artificial anisometropia, i.e., introduction of convex and concave spherical lenses in front of one eye can cause a blurring of one of the retinal images if the refractive power of the lens which is applied surpasses a certain threshold (about 0.75 diopter in our experiments). According to the above discussion concerning the factors causing aniseikonia of Type II, out-of-focus images in one eye will produce a "venetian blind" effect. Results of the measurements carried out with four observers are plotted in Figure 13, with anular disparity in seconds of arc on the ordinate axis. The abscissa shows the dioptric value of the lenses (convex lenses on the right; convex lenses on the left) which were placed before the right eye. Because of the observer's attempts to compensate for the effects of the lenses by accommodation, the results show a certain amount of scattering, particularly when lenses < 0.75 diopter are applied.

Application of cylindrical lenses in front of one eye shows essentially the same effects, if the position of the lens axis is 90°, whereas the effects of aniseikonia of Type II are practically absent with the lens axis at 0° (Figure 14).

The results obtained with spherical and cylindrical lenses clearly indicate that considerable disturbances of space perception and space discrimination can be caused by improperly adjusted spectacles which produce anisometropia.

Differences of retinal sensitivity in the two eyes can also be expected to produce the effects of aniseikonia of Type II. This is illustrated by Figure 15 which gives the angular disparity determined at regular intervals after bleaching the right eye with 300 foot-candles for a period of 10 minutes. The measurements are plotted over the time of recovery in seconds. As can be concluded from the graph, the spatial distortion due to aniseikonia of Type II attenuates during the phase of dark adaptation after monocular bleaching in the same rate as the sensitivity to light recovers. The general trend of the curve in Figure 15 is characteristic for the recovery of photopic vision as a function of time.

Conclusions

In view of the multidue of factors which can be expected to cause the special type of disturbances of space perception and space discrimination described in this paper, it appears evident that this effect merits consideration in the field of space perception. Furthermore, the possible existence of undesirable introduction of aniseikonia of Type II may become vital in cases where proper discrimination of space is essential (such as in aviation). Aniseikonia of Type II may also acquire a certain significance in clinical diagnosis. On the other hand, the effect may be utilized for devising a method of heterochromous photometry.

It may further be pointed out that the two types of aniseikonia rarely occur as isolated phenomena; to a certain extent both types appear simultaneously with one of the types being preponderant over the other, depending on the particular factor that is primarily responsible for the change of the objective or perceptive image size.

Acknowledgement

This paper was prepared in collaboration with Dr. Heinz Haber, Department of Space Medicine, School of Aviation Medicine, Randolph Field, Texas.

Bibliography

1. W. B. Lancaster, Arch. Ophth. 20, 907 (1938).

2. A. Ames, Jr. and G. H. Gliddon, Tr. Sect. Ophth. A.M.A., 1928, pp. 102-175.

3. A. Ames, Jr. and K. N. Ogle, Arch. Ophth. n.s. 7, 904 (1932).

4. A. Ames, Jr. and G. H. Gliddon and K. N. Ogle, Arch. Ophth. n.s. 7, 576 (1932).

5. A. Ames, Jr., K. N. Ogle and G. H. Gliddon, J. Opt. Soc, Am. 22, 538 (1932).

6. A. Ames, Jr. Am. J. Ophth. 18, 1014 (1935).

7. A. Ames, Jr., Am. J. Ophth. 28, 248 (1945).

8. K. N. Ogle, Researches in Binocular Vision. W. B. Saunders Co., Phila. and London, 1950.

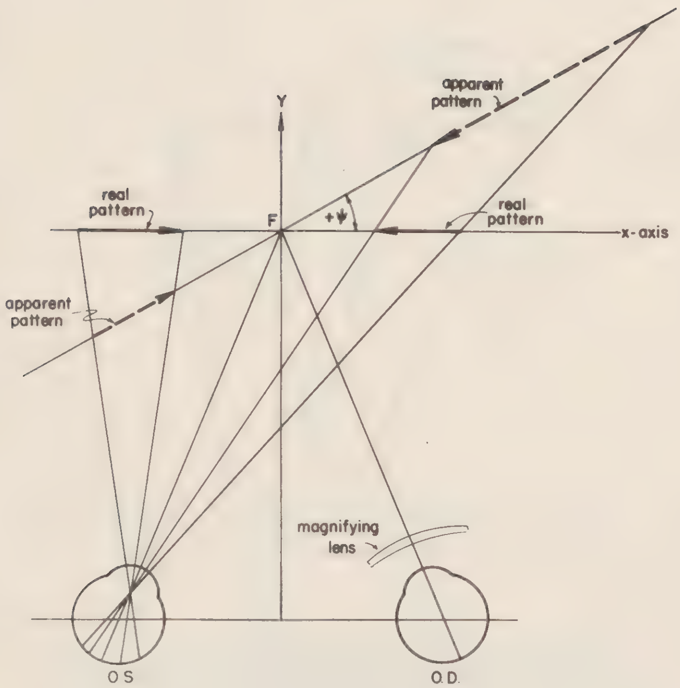


Figure 1

Apparent rotation of a fronto-parallel plane represented by two coplanar targets after interposition of a magnifying lens in front of one eye; after K. N. Ogle (aniseikonia of Type I).

Figure 2

Apparent individual rotation about individual pivot points of coplanar targets after interposition of a density filter in front of one eye (aniseikonia of Type II).

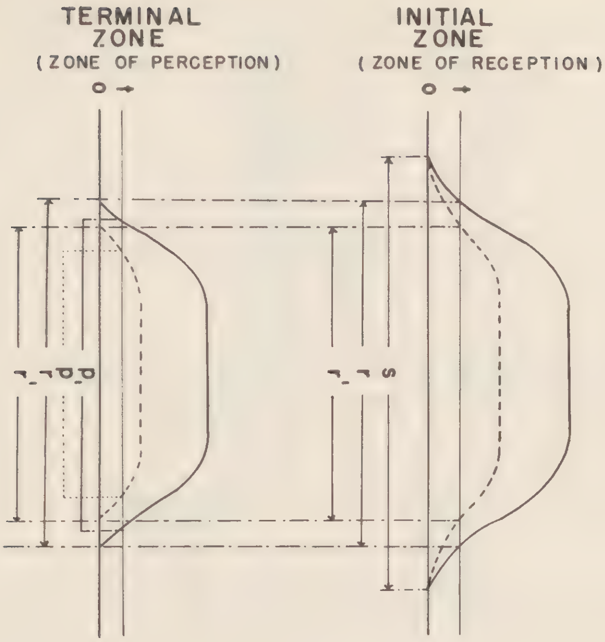


Figure 3

Relationship of retinal and perceptual images. For details refer to the pertinent paragraph of the text.

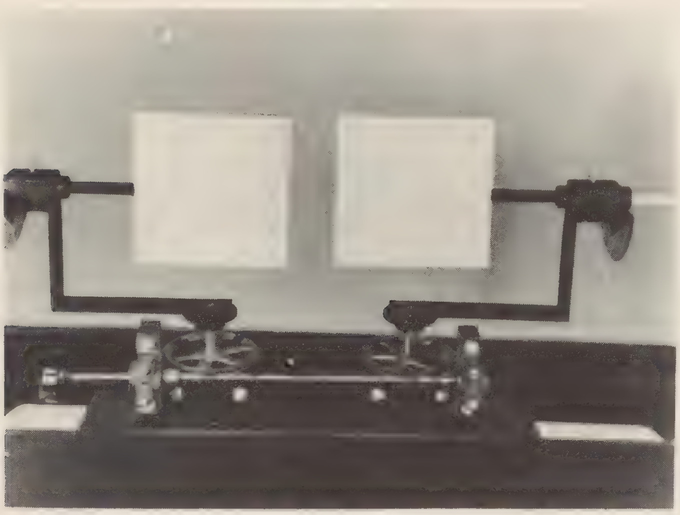


Figure 4

Apparatus used in the experiments consisting of two white square targets (12.8 x 12.8 cm) which are rotated about two individual vertical axes by the observer.

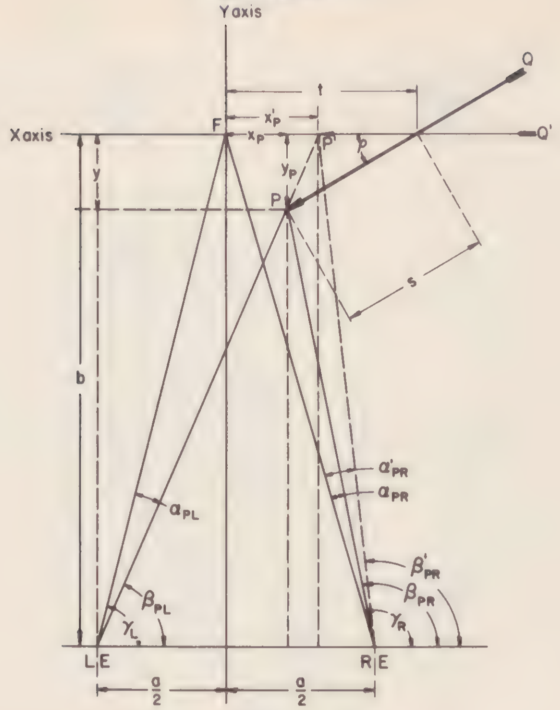


Figure 5

Denotation of quantities. Only the situation concerning the right target is drawn. PQ is the real target, P'Q' the apparent target. $\delta = \alpha_{PR} - \alpha'_{PR}$.

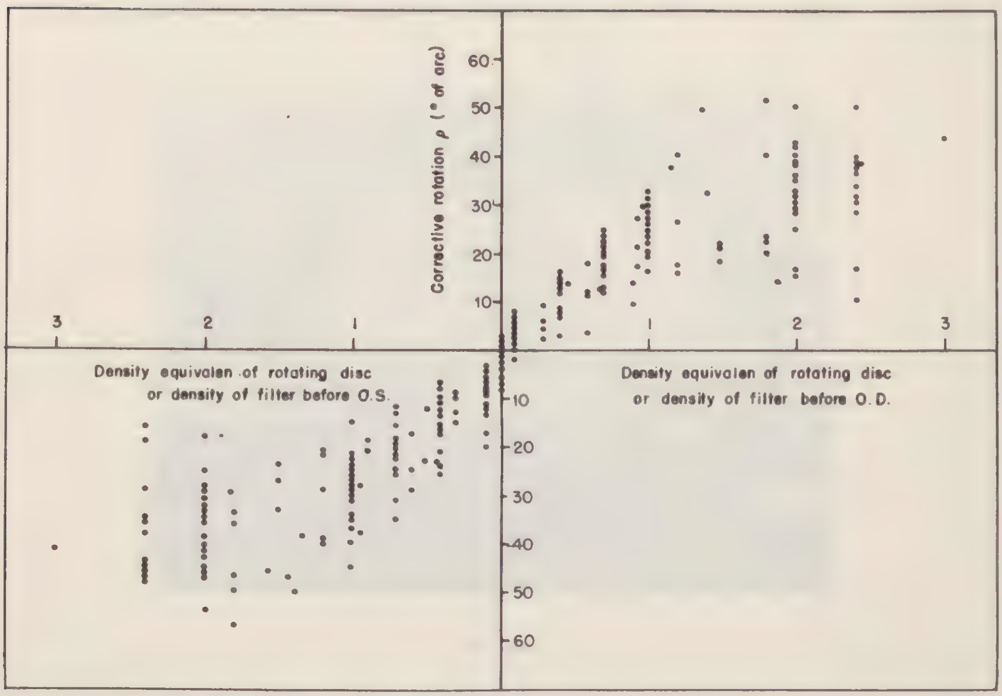


Figure 6

Scattered results obtained in 23 tests giving the apparent angle of rotation ρ (top) and the angular disparity δ (bottom) as functions of the density of the monocularly interposed neutral density filters.

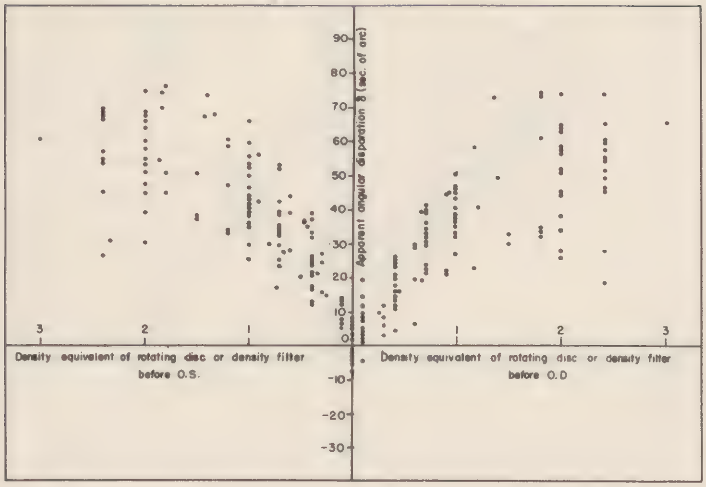


Figure 7

Arithmetic mean and standard deviation of the angular disparity δ as a function of the density of the monocularly interposed filters.

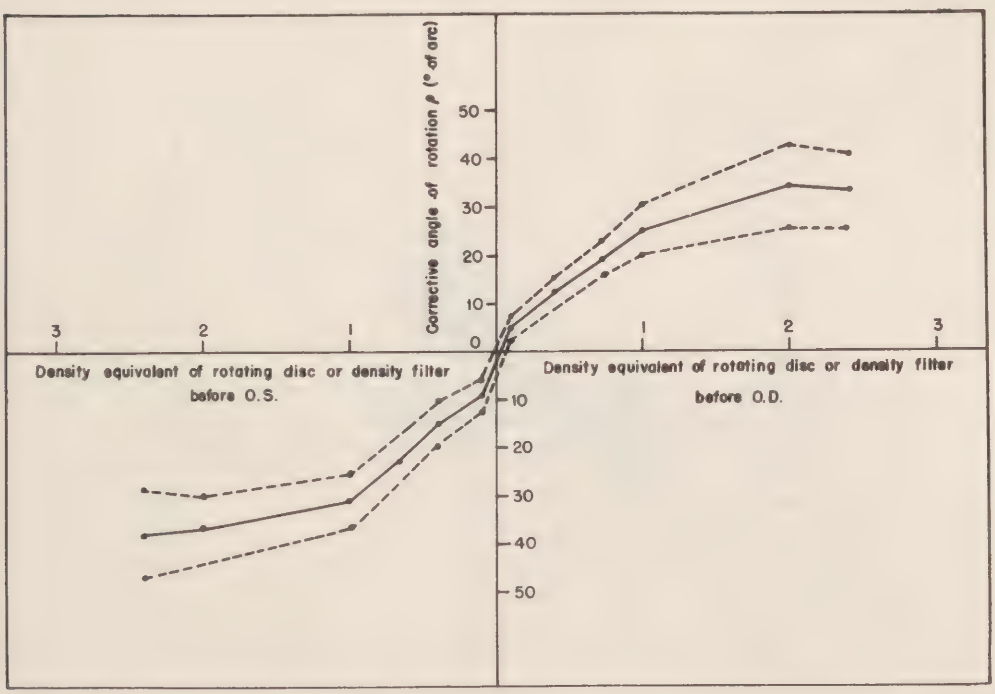


Figure 8

Scattered results of 23 tests giving the apparent angle of rotation ρ as a function of the density of monocularly interposed filters.

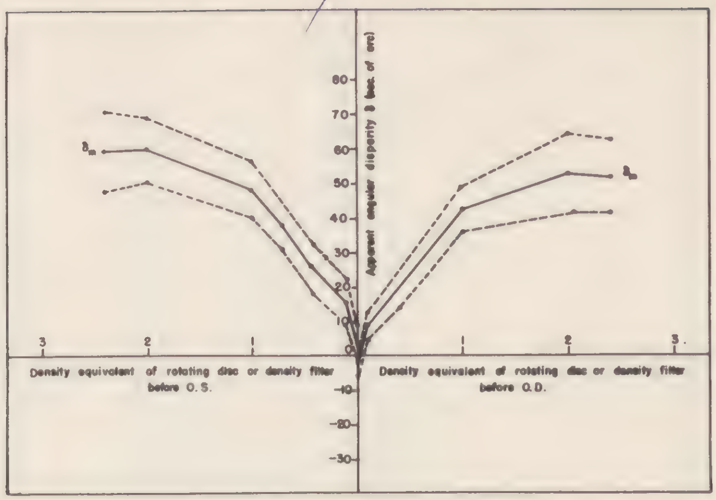


Figure 9

Scattered results of 23 tests giving the angular disparity δ as a function of the density of the monocularly interposed filters.

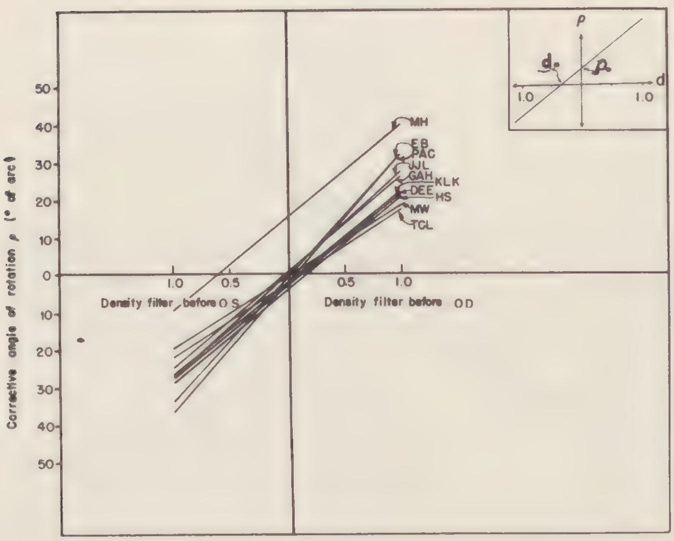


Figure 10

Linear approximations of the relationship between the apparent angle of rotation ρ and the density of the monocularly interposed filters for ten observers.

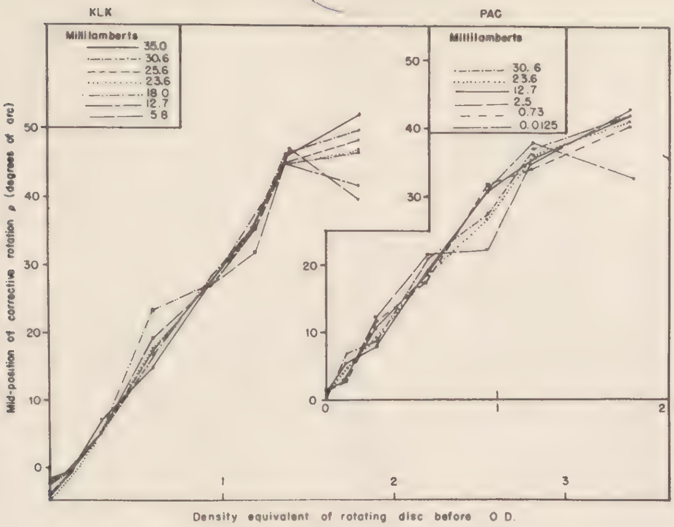


Figure 11

Apparent angle of rotation ρ as a function of the density of the monocularly interposed filters for different brightness levels of the targets (0.0125 to 35.00 millilamberts).

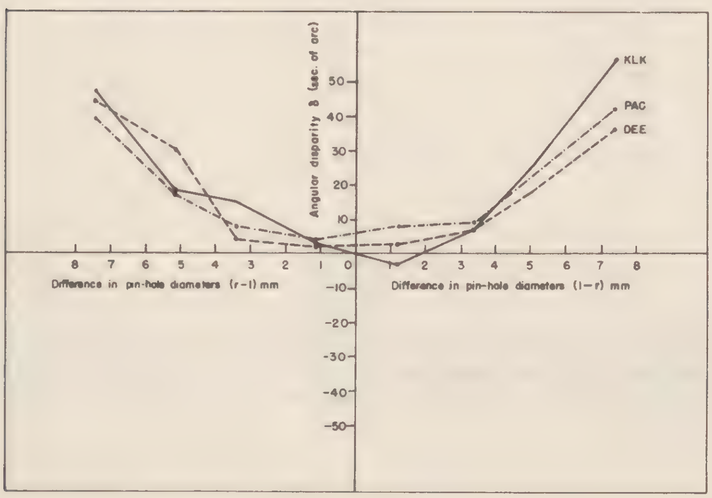


Figure 12

Relationship between angular disparity δ and the difference of pin-hole diameters in front of the eyes.

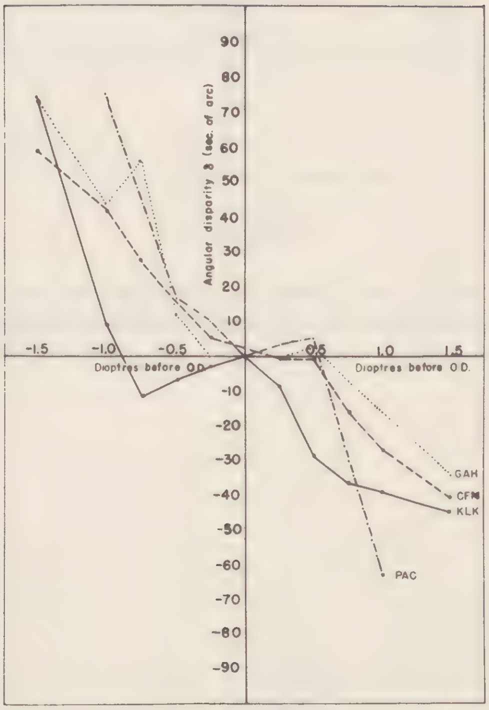
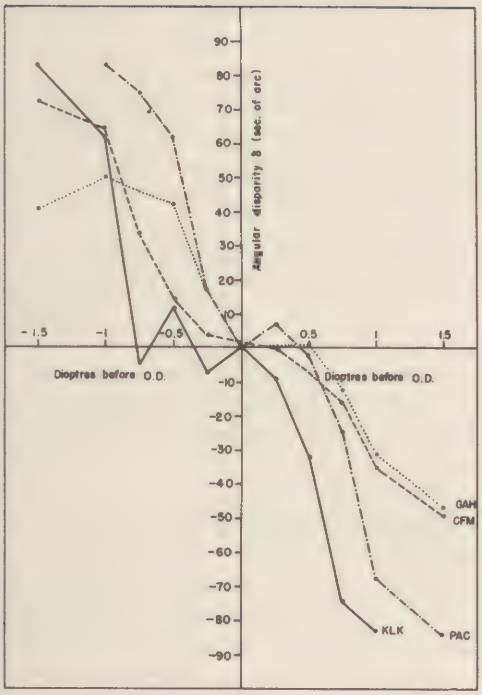


Figure 13

Angular disparity δ as a function of spherical lenses in front of the right eye.



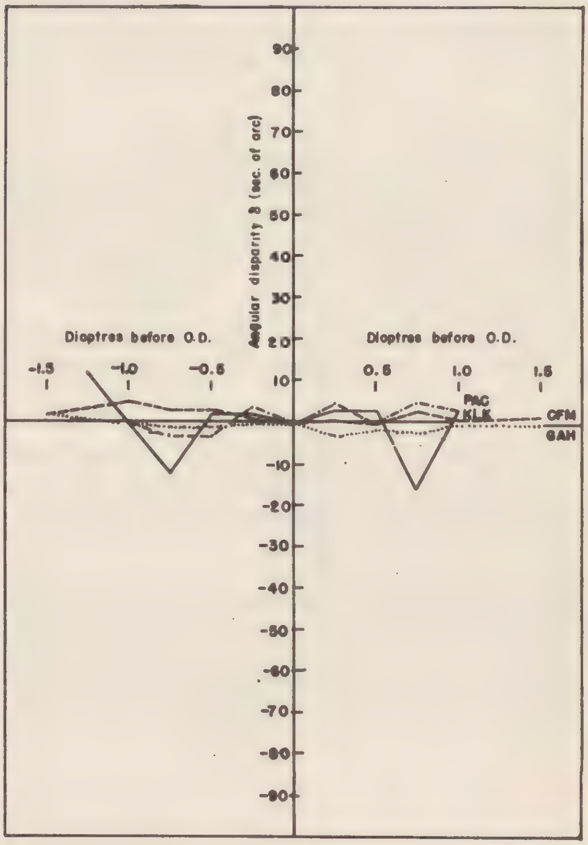


Figure 14

Angular disparity δ as a function of diopters of cylindrical lenses with lens axis at 90° (left), and with lens axis at 0°(right).

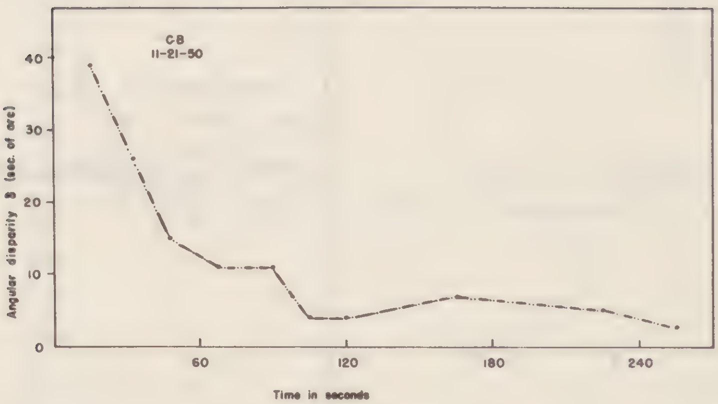


Figure 15

Angular disparity δ as a function of time in seconds after bleaching the retina with 300 ft. cdls. for ten minutes, depicting recovery of photopic vision in terms of aniseikonia of Type II.

Seeing-frequency with ultra-short flashes

W. J. Crozier and N. H. Pulling
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Abstract

An investigation has been undertaken to evaluate visual time-intensity thresholds at the fovea for single flashes of a green, 0.5-degree square target presented at exposure-times between 0.000012 and 0.0011 second.

An electro-optical shutter (manufactured by Baird Associates) was employed, with a specially-designed optical system. At each exposure-time a seeing-frequency curve was determined whose parameters, (1) intensity for 50-percent positive responses and (2) slope constant, describe statistically the visual effect of a short flash. Monochromatic light of 551mu was used for uniocular observation by two observers.

A hitherto unsuspected failure of the reciprocity law was demonstrated for exposures shorter than about 1 millisecond. An account of this work is in preparation for early publication.

A number of localized intensity maxima were found to be superimposed on the time-intensity contour within this range, as is true also for longer exposure-times. In each case they are correlated with striking changes in the slope indices of the seeing-frequency functions.

Whereas for exposures longer than about 0.000225 second seeing-frequency curves have been found to be logarithmic Gaussian integrals in the intensity required for constant effect, the curves for shorter exposures were found to be arithmetic. This transition corroborates a prediction by the senior author that this would result from inability of statistical elements of visual effect to vary in excitability during a brief flash.

DISCUSSION:

Dr. Fry asked whether comparison had been made between various kinds of mechanical light choppers and the optical gate which Mr. Pulling used.

Mr. Pulling replied that a mechanical chopper had been compared with an optical gate at the long end of the exposure range tested. No difference was found between the two types of choppers. Mr. Pulling also pointed out that the slopes of the seeing-frequency curves vary in a systematic way with exposure duration and that, therefore, it is possible to determine "where you are" on the duration axis on the basis of the slope of the seeing-frequency function.

Dr. Hulburt stated that it was his recollection that many years ago it was found that reciprocity of intensity and duration was found to be verified at very short flashes.

Mr. Pulling emphasized that in his experiment, reciprocity was not found. He stated that the energy levels were checked with a photomultiplier tube and it was perfectly clear that the flux present was not constant for threshold at various short exposures.

Dr. Bartlett stated that the earlier studies merely showed that it is possible to see very short flashes, but that they would not indicate the presence of a reciprocal relation between time and intensity.

An Evaluation of Four Psychophysical Methods for Determining the Difference Limen of Color.

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U.S.N. Submarine Base

Considering the vast amount of data collected by one or another of the psychophysical methods, there is surprisingly little evidence available from which to decide upon the most suitable method for a particular problem. The researcher, having collected his data by one psychophysical method, is very often not sure that he would have obtained the same result by another of the methods, or that he has not collected more data than would have been necessary to obtain the same degree of validity and reliability.

This problem of the selection of the psychophysical method faced us when we decided to make more detailed measurements than are available of the perceptible difference of chromaticity. There are two major determinations of liminal chromaticity differences for the whole color plane. Wright used a combination of the Method of Adjustments and the Method of Just Noticeable Differences. MacAdam used the Adjustments Method, requiring his observers to match the color of the standard with the color of the variable stimulus. The two studies, although they are in overall agreement, differ in quantitative details. We therefore decided to perform a separate experiment to obtain data on applicable psychophysical methods for this problem.

This report presents the results of a direct comparison of four standard psychophysical procedures applied to the judgment of color differences. In addition, the methods were applied under different surround brightnesses in order to evaluate the effect of surround contrast upon color discrimination as measured by the several methods.

The four psychophysical methods which we chose for evaluation were: Two versions of the Method of Constant Stimuli, Paired Comparisons and Adjustments.

The two methods of Constant Stimuli followed identical procedures, but differed in the instructions to the observer. The procedures used employed a fixed standard and equally spaced comparison stimuli falling at five steps in each direction from the standard along a line in the I.C.I. Chromaticity plane. Unlike the usual procedure, the comparison stimuli were not randomly presented from both sides of the standard, but each direction from the standard was explored separately, yielding a separate distribution of judgments.

The two versions of Method Constants we call Constants "same or different" where the observer was instructed to judge whether the comparison stimuli were the "same" or different" from the standard and Constants - "with direction" in which the observer identifies the end-point colors in each direction from the standard, let us say they are yellow in one direction from the standard and blue in the other direction. He then is instructed to judge whether each stimulus is "more yellow" or not more yellow than the standard or in the other direction "more blue" or "not more blue" than the standard.

The constants data were treated using the Urban weights and yielded D.L.s and standard deviations.

In the Method of Paired Comparisons, stimulus pairs were randomly combined from different places on the ten step scale in such a way that five separations of stimuli were repeated 25 times. These ranged from adjacent stimuli on the scale to ones five steps apart. The pairs were judged "same" or "different," and the distribution of "different" judgments over the five separation steps were weighted by the Urban process and yielded a limen or median, which is an average difference limen over the stimulus range employed.

In Method of Adjustments the observer was provided with a knob by which he could continuously vary the comparison color along the line of mixture of the two endpoint colors. The standard was the same as that used in the Constants methods. On each trial the variable stimulus was set randomly outside the range of uncertainty, and the observer was instructed to "match the variable stimulus to the standard."

The probable error of the distribution of matches was taken as the measure of sensitivity according to most frequent practice. The standard deviation was also computed.

The stimuli were produced by projection upon a white screen. The circular comparison field subtended $2^{o}4'$ of visual angle. It was centered in a square surround field which subtended $15^{o}10'$. The comparison field was divided vertically in semicircles which constituted the standard and comparison stimuli. Both were held at a brightness of 3.3 foot lamberts through all stimulus steps. The surround was varied from session to session in 4 brightness steps yielding contrast ratios of 3:1 to the comparison field 2:1, 1:1 and .05 to 1.

Figure 1 shows an I.C.I. plot of the line in the chromaticity plane along which the colors we studied range. A and B are the endpoint chromaticities. A falls in the blue-green region, B in the yellow-green region. The stimulus range about the standard S which was required to go from close to 0% "different" judgments to close to 100% "different" judgments was small as compared with the total distance between the endpoints.

Four observers were used. All had considerable experience in psychophysical estimation, all were color normal as determined by tests with the American Optical Company Pseudo-Isochromatic plates, the Farnsworth-Munsell 100 Hue Test and the New London Double Wedge anomaloscope.

Data was collected following a four by four latin square plan which provided a different combination of psychophysical method and surround brightness to each observer, thus balancing serial effects and possible extraneous influences from session to session. Table I illustrates this experimental plan. Observers are represented by arabic numerals; surround contrasts by Roman numerals; and psychophysical methods by letters.

The analysis of variance permitted the separate treatment of methods effects, contrast effects and inter-observer differences. By repeating the latin square an estimate of test-retest variability was afforded as well as an error term independent of residual variance, allowing us to test the significance of interactions.

The analysis of variance is summarized in Table II. The error term which was used in all F tests was the within-subclass variance. This term is the average variance contributed within subjects and within methods by variability from one testing to the next. Thus, in evaluating methods differences, we are asking whether the variability between methods is significantly greater than the variability of the same observer under the same conditions from one testing to the next. It is the closest thing in this arrangement to testing whether those differences are significantly greater than chance variability.

We may see in the last column that the differences between observers were significant

at the 1% level, as were the differences between psychophysical methods. The variation of surround contrast produced no significant effect upon the magnitude of the difference limen.

On line 5 the interactions over the entire latin square are tested and it may be seen that these were not significant. That is, in no case were one or more methods unduly affected by the particular combination with certain contrasts or with certain observers.

It was possible to analyze the contribution of each psychophysical method to the total within-subclass variance. Thus, we have an estimate of the relative variability from one testing to the next of each method. The methods arrange themselves in the following order of decreasing variability. The most variable was Method of Paired Comparisons, then, Constants "same or different," then Constants "with direction" and the least variable from one testing to the next was Method of Adjustments.

Having discussed the relative test-retest variability or reproducibility of each method, we now turn to another criterion for evaluating them. This is precision. That is, with what certainty can we quote the difference limen as representative of a set of observations? This we can measure by the deviation of the observations about their central tendency - the mean or median. We found that Paired Comparisons showed the largest standard deviation - thus the lowest precision. Method of Constants "with direction" showed the lowest standard deviations, thus the highest precision.

The last point upon which we obtained information about the four methods was the size of the D. L. We showed in the analysis of variance that there were highly significant differences in the size of the D. L. between all four methods. Let us now examine the differences in size of the D. L. between individual methods.

In Figure 2, the average D. L. for 4 observers is plotted for each method.

Having found these differences in size of the D. L. between the methods using the same observers, judging on the same stimuli, we have attempted to look behind the empirical results for the source of these differences. The first and most obvious things to look for were the differences which resulted from the way in which the measure is generalized from the raw data, that is, in the mathematics of computing the limen from the judgments.

Since the two methods of constants employed the same mathematical procedures, the differences there must be ascribed to procedure and instructions.

We believe that Paired Comparisons is mathematically comparable to the method of constants, provided that discrimination does not change over the stimulus range employed. Paired Comparisons differs from constants only in that each stimulus in the series is used as a standard in turn rather than the use of a fixed standard midway in the series. If the function were the same over the stimuli employed, one of each pair of stimuli could be equated to the standard of constants and the resulting ogive would be mathematically identical with the Constants function.

Method of Adjustments, however, does not agree mathematically with the Constants or Paired Comparisons Methods. In Figure 3 are drawn the theoretical curve of errors of match by Adjustments and the theoretical normal ogives to be expected from our Method of Constants. The unit normal curve is drawn to represent the distribution of matches in Method of Adjustments, starting at 0 standard units, the mean of the normal curve which is assumed to fall at the standard S - symmetrical normal ogives are drawn to represent the expected didstribution of "different" judgments from Method of Constants. We have stopped the normal curve at $\pm$ 3 standard deviations. The ogives are drawn to fall sym-

metrically within the 0-3σ interval. Their standard units are represented in the scale at the top. It may be seen that the 1 P.E. of Adjustments falls well within the limen of constants as does the 1 σ of adjustments, both of which have been used as the measure of discrimination, the former more frequently. Making the above assumptions, 1.5 S.D. of the Adjustments curve agrees with the limen of Constants.

In a preliminary test of this relationship, we have gone back to the data collected in this study, converted the adjustments measure to 1.5, and have reentered the analyses of variance with these values. We find that the sums of squares for methods difference is reduced from 22.17 to 11.81, yielding an F ratio with the within-subclass variance of 6.91 which remains significant at the 1% level. If we test the significance of the difference between individual methods we find that the 1.5 σ of adjustments falls in magnitude, between that of the Constants same or different D.L.s and those of Paired Comparisons, D' in Figure 4.

Constants "with direction" now yields the smallest measure of discrimination. At least on a preliminary basis, we believe that these now represent comparable magnitudes of the measure of discrimination as yielded by the 4 methods.

In conclusion, we have found that Method of Adjustments and Constants "with direction" are better reproducible and more precise than Paired Comparisons and Constants "same or different."

We have found no significant effect of variation of surround-to-target contrast upon the magnitude of the Difference Limen.

We have begun an analysis of the source of differences in the magnitudes of the discrimination measure yielded by the four methods with the consideration of differences contributed by the mathematics of computing the D.L.

TABLE I

Four by four Latin square design employed in studying effects of psychophysical method, surround contrast and observer differences upon the difference limen of chromaticity.

Surround to Target Contrast

		I 3:1	II 2:1	III 1:1	IV .05:1
Observers	1	A	B	C	D
	2	B	A	D	C
	3	C	D	B	A
	4	D	C	A	B

A - Method of Constants - "Same or Different"
B - Method of Constants - "With Direction"
C - Method of Paired Comparisons
D - Method of Adjustments

Table II - Completed Analysis of Variance

Urban D.L.'s and 1 P.E. of Adjustments

	Source	SS	DF	$V(M^2)$	F	P
1	Between Observers	9.24	3	3.08	$\frac{V_{obs.}}{V_{ind.\,Error}} = \frac{3.08}{.56} = 5.50$	$P < .01$
2	Between Background Contrasts	.13	3	.04	$\frac{V_{illum.}}{V_{ind.\,Error}} = \frac{.04}{.56} = .07$	$P > .05$
3	Between Methods	22.17	3	7.39	$\frac{V_{meth.}}{V_{ind.\,Error}} = \frac{7.39}{.56} = 13.20$	$P < .01$
4	Within-subclass variance (Independent Error)	9.02	16	.56		
5	Subclass-Discrepancy (Interactions)	6.82	6	1.13	$\frac{V_{subcl.\,Discrep.}}{V_{ind,\,Error}} = \frac{1.13}{.56} = 2.02$	$P > .05$
6	Total	47.38	31			

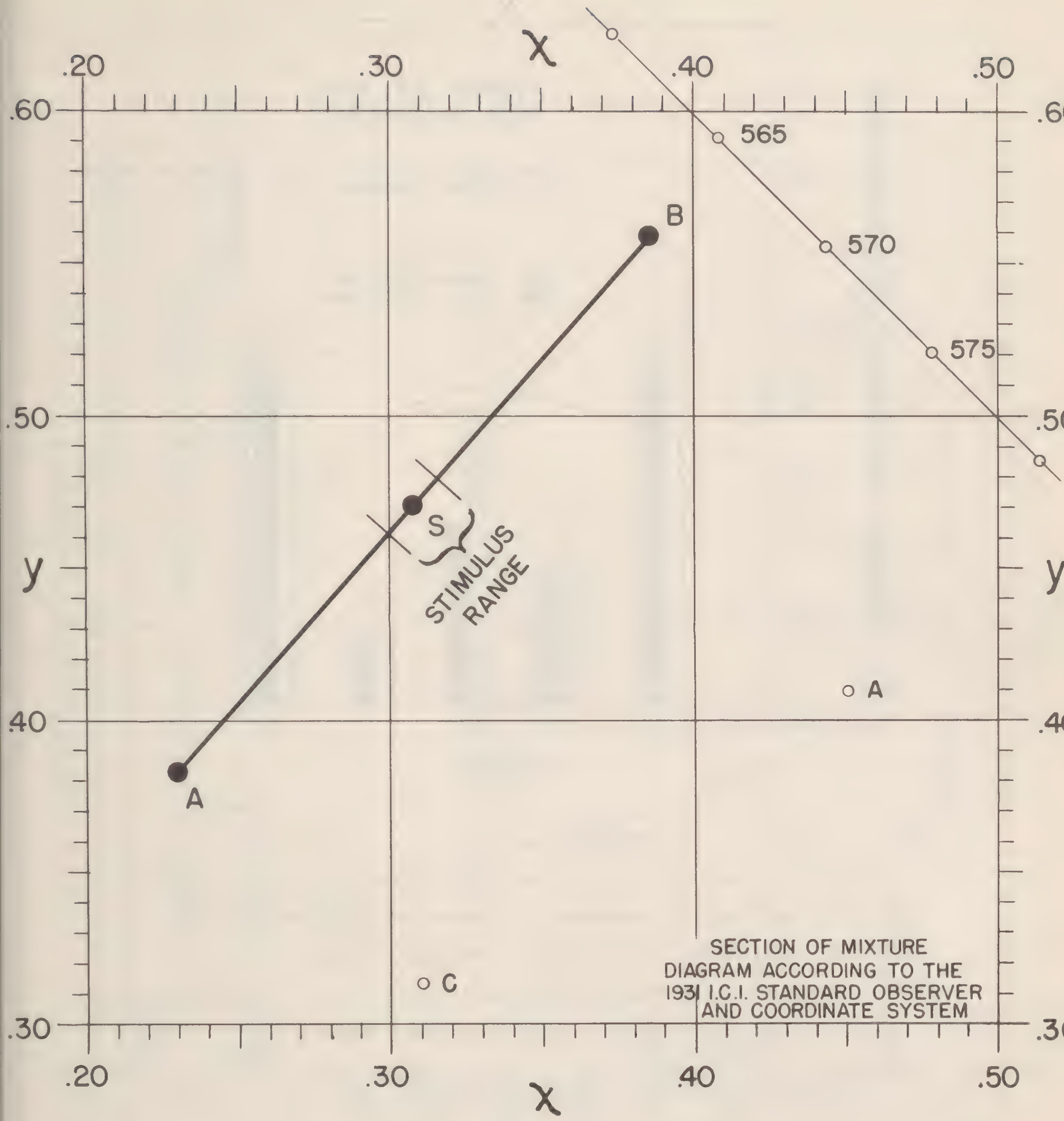


Figure 1

I.C.I. Plot Showing End-point Chromaticities A and B, Standard S and Stimulus Range

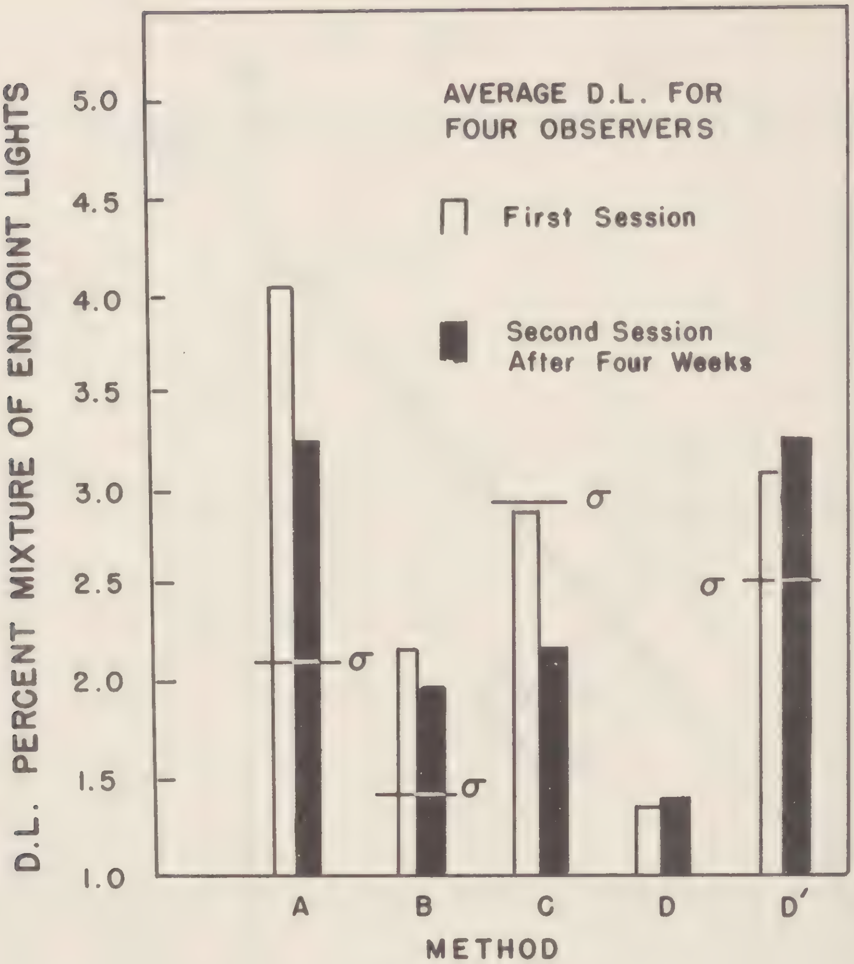


Figure 2

Average D.L. for Four Observers

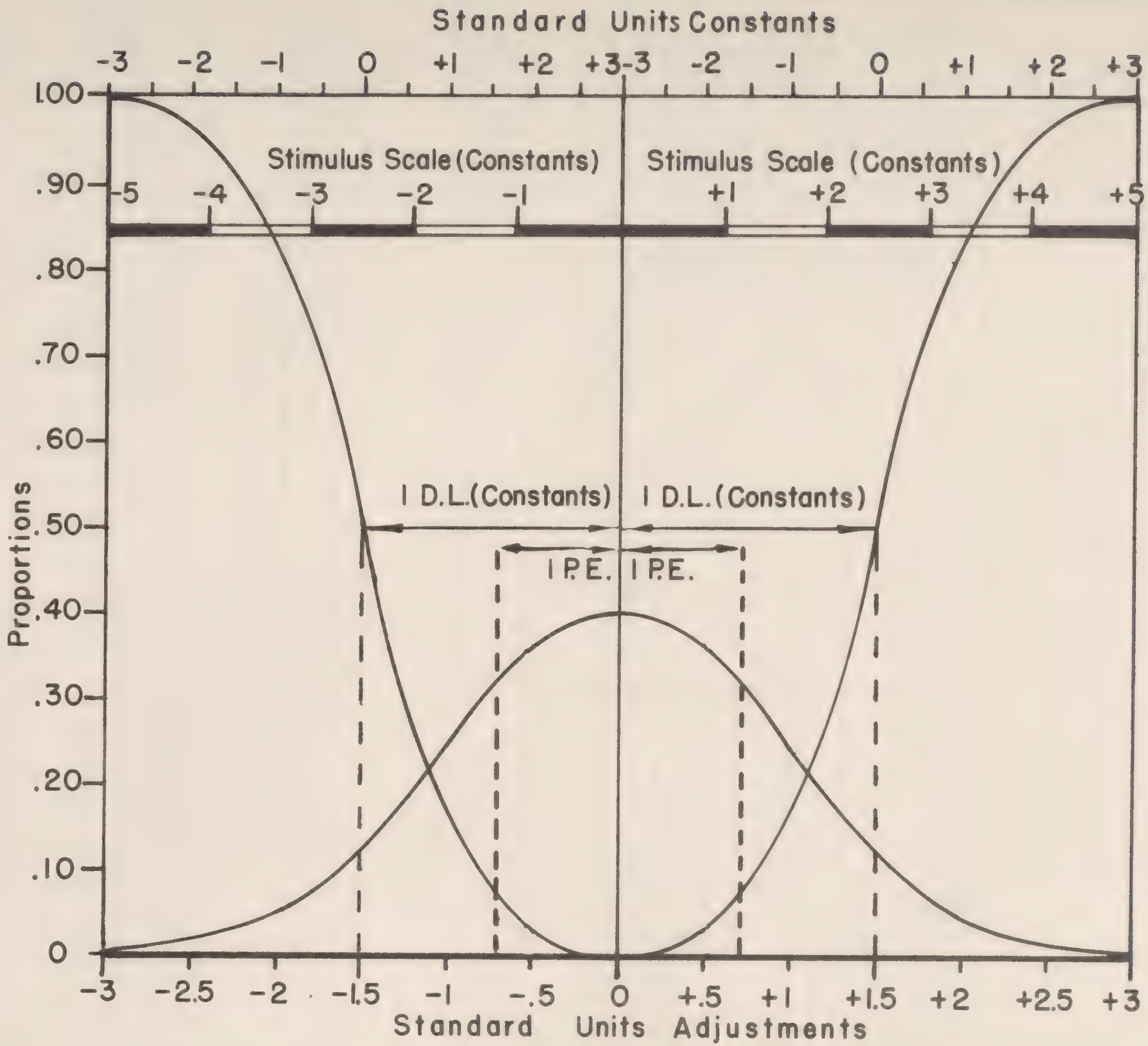
A - Method of Constants - "Same or Different"

B - Method of Constants - "With Direction"

C - Method of Paired Comparisons

D - Method of Adjustments (Average Error) using 1 P.E.

D'- Method of Adjustments using 1.5



THEORETICAL CURVES FOR METHOD OF CONSTANTS AND METHOD OF ADJUSTMENTS

Figure 3

Visual Performance As A Function Of The Brightness Of The Immediately Preceding Visual Task

S. D. S. Spragg
University of Rochester

The experiments which I wish to report today were carried out with the assistance of Mr. Joseph W. Wulfeck. They are part of a research program on visual performance at low photopic brightness levels, which we are carrying out on a research contract with the Aero Medical Laboratory, Air Materiel Command.

Previous research in this program (7.8) has studied the speed and accuracy of dial reading performance as a function of the quantity and quality of dial illumination. The brightness range employed was from .005 foot lamberts (slightly above cone threshold) to 6.0 foot lamberts. The results of that study can be summarized briefly by reference to Slide #1 which shows the meantime required to read a bank of 10 instrument dials at each of the brightness levels used. Results are shown both for the 2.8 inch 100 x 10 dials and for the smaller 1.4 inch 100 x 1 dials. The results when presented as accuracy scores follow very closely these time curves. Both the accuracy and the time scores suggested a critical brightness level at about .02 foot lamberts, below which performance becomes significantly poorer as brightness is decreased, and above which performance does not improve significantly with increases in brightness.

On the basis of these results it was recommended that if airplane instrument dials were illuminated so that their brightness was just above .02 foot lamberts this would be sufficient for adequate visual performance in the cockpit and would at the same time maintain dark adaptation to a greater degree than if higher dial brightness levels were permitted.

A subsequent experiment by Kappauf (2) provided a general corroboration of this critical brightness level for visual perceptual tasks, and a recent study by Crook (3) has duplicated almost exactly the value for the critical brightness level which we found for a visual addition task (6). The existence of a critical brightness level for visual perceptual tasks of this nature seems then to be rather well established.

Night operations of many kinds, including night contact flying, make conflicting visual demands on the operator or pilot. The pilot for example must have sufficient illumination for adequate cone vision within the cockpit, especially for instrument dial reading. On the other hand he must be well dark adapted so as to detect and discriminate visual objects of low brightness and low contrast outside the cockpit. The two kinds of visual tasks may at times be demanded in rapid succession.

Our present experiments are directed at the problem raised by this dual nature of the pilot's task. Specifically, we are attempting to determine how visual performance at low photopic brightness levels is related to the brightness of an immediately preceding visual task.

Apparatus and Materials

Slide #2 shows the essential parts of the apparatus used for these experiments. The subject sits inside a darkened booth with his forehead against the head-rest. The dials are presented at a distance of 28 inches and 15 degrees below his horizontal line of regard. They are illuminated by diffuse light from two lamp housings, one on each side of S's head. Brightness levels are controlled by a series of precisely drilled brass diaphragms.

Above the dials and on the subject's horizontal line of regard is a window through which he views periscopically the far task by means of two front surface mirrors. The far field is at a distance of 18 feet and is trans-illuminated by diffused light from a lamp housing beneath it. The brightness of the far field is controlled by diaphragms and by Wratten neutral density filters.

Stimulus materials for the dial reading task were banks of 12 high contrast photographic reproductions of instrument dials. The dials were 2.8 inches in diameter and the scale was 100 x 10. The far task consisted of banks of 9 Landolt rings with the breaks in the rings placed randomly at the four compass points. The rings were precision cut from uniform density film and mounted on glass plates; the contrast between rings and field was of the ratio of 1 to 4. The break in each ring subtended 5 minutes of visual angle at this viewing distance.

Light sources were monitored at a constant level of 100 volts, yielding a color temperature of approximately 2400° K. Three levels of brightness were established for the dial reading task: 2.9, .083, and .005 foot lamberts. Five levels were used for the Landolt ring task: 6.0, .076, .01, .007, and .0035 foot lamberts.

Experiment I

In the first experiment S's task was to read a bank of 12 instrument dials at the near (28 inch) distance at one of the three brightness levels, then immediately "read" the bank of 9 Landolt rings at the far distance at one of five brightness levels. Dial illumination was extinguished, and the bank of rings was illuminated simultaneously as soon as S read the 12th dial. A latin square design was used so that each subject performed the dial-to-ring sequence under every combination of brightnesses.

Fifteen high school seniors, screened to rigorous visual standards by an Ortho-rater examination, served as subjects. They were made thoroughly familiar with the experimental materials and procedures. At the beginning of each of his three experimental sessions, S was given standard instructions (stressing speed and accuracy), preliminary practice, and was cone dark adapted to the level of brightness being used for the near (dial) task.

At each of this three experimental sessions each S performed 5 dial-to-ring sequences under each of five of the 15 possible combinations of dial and task brightness. As in our previous studies, time and error data were recorded for the middle 10 of each bank of 12 dials. Time and error scores were recorded for the Landolt ring task but, except at the lowest ring brightness level, errors were almost non-existent on the ring task, thus our principal data are time scores.

The results of this experiment are summarized in Slide #3. Since our primary interest is performance on the second task (the Landolt rings) the ordinate of the graph represents mean time in seconds to "read" 9 Landolt rings. The abscissa is in terms of the brightness of the first task (dial-reading) and the three dial brightnesses used are indicated by appropriate marks on the base-line. Each of the 5 curves, therefore, shows reading time on the ring task as a function of the brightness of the ring field, and also as a function of the brightness of the immediately preceding dial reading task.

Two aspects of the results are evident from this graph. The first is that performance on the ring task does not become markedly poorer as the brightness of that task is decreased from 6.0 to .076 foot lamberts, but does show marked impairment as ring field brightness is reduced below the .02 foot lambert level which our previous studies showed to be a critical value.

The second and, from our present standpoint, more interesting finding is the fact that these five curves are essentially flat. Note that in those cases where there is some hint of a slope (the two uppermost curves) it is not in the direction that would be expected. These results show that performance on the second task is essentially a function of the brightness of that task and is not functionally related to the brightness of the immediately preceding dial reading task.

Experiment II

In this experiment the order of the tasks was reversed so that S first "read" 9 Landolt rings at the far distance then immediately shifted to reading 12 instrument dials at the near distance. All other aspects of the procedure were the same as in the first experiment. Twelve college students, visually screened as before, served as subjects.

Slide #4 summarizes the results of this experiment. Since we are again interested in performance on the second task the ordinate of the graph represents mean time to read the middle 10 of each bank of 12 dials. The abscissa represents brightness of the first task (the Landolt rings) and the 5 brightness levels used for that task are shown by appropriate marks on the baseline. Each of the three curves thus shows time required to perform the dial reading task as a function of the brightness of the dial task and also as a function of the brightness of the immediately preceding ring task.

Again, two aspects of the results stand out. A critical brightness level in visual perceptual tasks is once more indicated by the impairment shown for the .005 curve as contrasted with the .083 curve. More striking, however, is the essential flatness of these three curves. No point on any of these curves differs from any other point on that curve by an amount sufficient to be significant at even the 10% level of confidence.

Experiment III

Because of the possibility that some time differences might have been hidden by scoring only the middle 10 of each bank of 12 dials, the experiment was repeated on four subjects and times were recorded for all 12 of each bank of dials. The results, summarized in Slide #5, which presents the data in the same manner as the preceding slide, constitute a close corroboration of the preceding experiment. Dial reading performance is related to the brightness of the dial task, but bears no functional relation to the brightness of the preceding ring task.

Discussion

What should be said about these results? We have presented evidence that performance on a far visual perceptual task is unaffected by the brightness of an immediately preceding near visual task, and similarly that performance on a near task has no functional relation to the brightness of the immediately preceding far task. At first blush one might be tempted to say that there is no such thing as dark adaptation. Our results do not, of course, justify any such conclusion. They are a function of the restricted range of brightnesses which we used.

These experiments are quite similar to those which have studied the course of dark adaptation as a function of the brightness level of the pre-adapting stimulus field. We can think of the brightness of the first task as a kind of pre-adapting brightness. And instead of asking, as we did, how long it takes to perform a given visual task after varying levels of pre-adapting brightness, we might very well have asked how bright a given visual task must be in order to be performed immediately, following various levels of pre-adapting brightness. This is a kind of instantaneous threshold.

Our pre-adapting brightnesses ranged from 6.0 to .0035 foot lamberts. The lowest level at which the second task was presented was .0035 foot lamberts. Most dark adaptation studies have used pre-adaptation brightnesses very much higher than these, often at several hundreds or even thousands of footlamberts. Only in a few instances have relatively low preadaptation brightness levels been used and the data from these are not as clear as we could wish. If, however, we attempt a generalization on the basis of studies by Haig (4), Blanchard (1), Peckham (5), and others, two facts are prominent. First, the instantaneous brightness threshold decreases rapidly with a decrease in pre-adapting brightness, and second, the course of dark adaptation is increasingly rapid with decreasing pre-adapting brightness.

If we relate our present findings to the first of these two facts, we find that for a pre-adapting brightness in the range of our highest values (3 to 6 foot lamberts) the instantaneous threshold lies over a log unit below the lowest value that we used on our second task (i.e., .0035 foot lamberts). With lower levels of pre-adapting brightness the instantaneous threshold would be even lower.

With regard to the second fact mentioned above, namely the increasing rapidity of dark adaptation with decreasing pre-adaptation brightness, we find that the sensitivity of the eye increases so rapidly after pre-adapting brightnesses as low as ours that the threshold, after only 10 to 15 seconds, would be from 2 to 3 log units below the lowest value of our second task.

Thus we can understand that the use of pre-adapting brightnesses within the low and restricted photopic range of our experiment has so little effect upon performance on the second visual task in our situation, since even after exposure to our highest pre-adaptation brightness, the instantaneous threshold is sufficiently low to permit adequate performance at the lowest brightness used for our second task.

From the point of view of application, our findings should have usefulness in connection with the specification of instrument dial brightness for night operations. Our brightness values, although restricted, do cover a range of over 3 log units, and at the upper limit involve values which represent a fairly high level of instrument dial brightness. It would seem that precautions to have instrument dial brightnesses just barely above the critical .02 foot lambert level are unnessary. A level of brightness one or even two log units above this level would provide a good factor of safety, adequate illumination for dial reading, and no interference with visual tasks outside the cockpit, at least down to cone threshold levels.

References

1. Blanchard, J. The brightness sensibility of the retina. Phys. Rev., 1918, 11, 81-99.

2. Chalmers, E. L., Goldstein, M., and Kappauf, W. E. The effect of illumination on dial reading. USAF, Air Materiel Command. AF Technical Report No. 6021. August, 1950.

3. Crook, M. N., Harker, G. S., Hoffman, A. C., and Kennedy, J. L. Effect of amplitude of

apparent vibration brightness, and type size on numeral reading. USAF, Air Materiel Command. AF Technical Report No. 6246. September, 1950.

4. Haig, C. The course of rod adaptation as influenced by the intensity and duration of pre-adaptation to light. J. gen. Physiol., 1941, 24, 735-751.

5. Peckham, R. H. The course of readaptation after exposure to white light. U. S. Navy, School of Aviation Medicine, Pensacola. February, 1944.

6. Rock, M. L. Visual performance as a function of low photopic brightness levels. USAF, Air Materiel Command. AF Technical Report No. 6013. November, 1950.

7. Spragg, S. D. S., and Rock, M. L. Dial reading performance as related to illumination variables. I. Intensity. USAF, Air Materiel Command. Memorandum Report MCREXD-694-21. October, 1948.

8. Spragg, S. D. S., and Rock, M. L. Dial reading performance as related to illumination variables. III. Results with small dials. USAF, Air Materiel Command. AF Technical Report No. 6040. November, 1950.

Improved Visual Aids for the Night Task of the Landing Signal Officer

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Aircraft carrier flight operations are carried out through the use and coordination of a complex assortment of specialized human skills which are essential despite the mechanical efficiency of the devices provided to accomplish the mission of the carrier. First and foremost among the highly trained personnel required are, of course, the pilots. Another of the specialized and highly skilled personnel, who rivals the pilot in certain aspects of the psychological and physiological performance qualities required, is the individual filling the critical and unique position of the Landing Signal Officer.

The Landing Signal Officer, the LSO, has the function, from his station on a platform on the port quarter of the carrier's flight deck, of exercising considerable judgment in interpreting his visual, auditory and other perceptions to guide approaching aircraft to a safe recovery aboard the carrier. He conveys his guidance information to the pilot of the approaching aircraft by means of hand-held signal flags.

It is apparent that the aircraft carrier approach procedure, as it is organized, is largely dependent upon a high level of training on the parts of the pilot and the LSO. For the pilot, the training enhances his skill in carrying out the downwind, base and the initial part of the approach legs by himself through the use of external visual cues and the aircraft's instrumental displays. In the latter part of the approach leg, about three thousand feet, the pilot's skill includes the proper interpretation and fulfillment of the LSO's instructions. During this phase it is, of course, essential that the pilot secure an accurate visual impression of the signals being conveyed by the LSO and at the same time continue to maintain some contact with his instrumentation and with the external environment. With regard to the latter, the pilot needs as accurate an estimate as he can manage of the several qualities of the flight deck surface and his aircraft's relationship to it. Included would be its distance, his approach angle to it, his lateral position with respect to it, etc. For the aircraft designer this means providing a maximum of unrestricted, undistorted vision through the aircraft canopy. Our laboratory is at present engaged in a study to develop physiologically and psychologically adequate criteria for determining unacceptable amounts of windscreen distortion. It is recognized that performance in the critical phases of aircraft carrier landings can be seriously affected by distortion levels which are ordinarily not too disturbing.

Further to assist in the provision of maximum guidance for the pilot much more needs to be done to make the flight deck visually effective and to give the LSO better means of conveying his instructions. Better schemes of deck painting and lighting are being studied and consideration is being given to sharply defined light beam approach path projectors. For increasing the recognizability of the LSO's signals the conspicuity of the LSO has been increased by use of ultra-violet activated fluorescent cloth strips for his body and arms and by the use of fluorescent signal flags. As a corollary to this lighting technique, it is necessary to provide adequate protection for the LSO's eyes to the end that the ultra-violet radiation does not create a serious hindrance to his ability to carry out his visual search function. To this end our laboratory

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The viewpoints expressed in this paper are those of the authors and are not intended to represent those of the Department of the Navy.

has designed a protective shield extending out from the upper lip to the distance found necessary to shield the light from the eyes of the LSO. Since the LSO is in a hazardous location, provision has been made for collapse of the shield should a moderate force be applied to it. Another way in which LSO signal conspicuity may possibly be improved, and at the same time remove the LSO from his exposed location, is through a mechanical or electrical signal panel controlled remotely by the LSO. Such a 'mechanical LSO' has been developed and is showing some promising possibilities in tests now underway.

Up to this point we have discussed aspects of the visual difficulties involved in carrier landings which are largely concerned with the pilot's ability to procure maximally useful visual perceptions. However, that is far from being the only important aspect of the technique. Since the critical, final stages of aircraft recovery aboard a carrier require the important skills of the LSO as well as those of the pilot, the manner in which the LSO perceives, interprets, and utilizes the significant information concerning the approaching aircraft assumes major importance.

What does the LSO do? In summary, he provides a visual indication to the pilot which conveys the LSO's judgment as to whether the deck is ready and whether the approaching aircraft is in proper condition, in the proper flight path, and at the proper flight attitude for a safe recovery. Finally, at the proper moment, the LSO determines whether an engine "cut" may be made or a "wave-off" should be given.

The LSO's interests related to the aircraft are, then, in three general areas:

(a) He desires to know at sufficient distance to provide adequate warning whether the aircraft is in condition for landing. Are the wheels and hook down? Are the external stores in safe condition? During the day this information is provided by direct visual examination by the LSO or by his assistants who convey information to him vocally.

(b) The LSO is concerned with the approach flight path of the aircraft and its relationship to the flight deck. Is the aircraft too high, too low, or too far to either side? Will the pilot be able to rectify any discrepancies of this nature in time to approach the deck with the proper attitude? During sufficiently clear day conditions these determinations can be based upon the LSO's direct visual examination of the aircraft.

(c) The aspect of approach which requires the utmost of trained skill for proper evaluation is that of the orientation of the aircraft so that it is operating within the proper margins above the stalling angle-of-attack for the particular airplane. If the angle-of-attack is just right, the aircraft can be brought to a position about 15 to 20 feet above the carrier deck, the pilot can receive and comply with a "cut engine" signal, and then can maneuver the aircraft so that the hook engages the arresting cables on the flight deck.

In determining this last aspect of the quality of the approach, the LSO, in daylight, is faced first with the crucial task of knowing at what angle-of-attack the particular aircraft type will stall. The angle-of-attack is the angle made by the mean chord line of the aircraft with the relative wind. Second, he must know how much angle beyond this stall angle the aircraft should maintain to be within the limits required for a good approach.

Another parameter of flight is the pitch attitude angle of the aircraft. This angle is made by the longitudinal axis of the aircraft with the horizon. The pitch attitude bares a fixed relationship to the angle-of-attack when the aircraft is in level flight. Thus, attitude may be used to indicate angle-of-attack when an aircraft is in level flight.

Air speed is also related to angle-of-attack in that for any particular type aircraft and for any one condition of loading, airspeed is fixed for any angle-of-attack. For modern

type aircraft airspeed is an unsatisfactory guide to angle-of-attack because fuel, ammunition and external stores loading can and does change rapidly. Whereas the pilot utilizes airspeed in the early stages of approach for getting the aircraft roughly into the proper attitude, this is not a reliable guide without precise loading information for the final stages.

In current practice the aircraft is in level flight during most of the approach. Therefore, for visual examination purposes in daylight, the attitude of the approaching aircraft, in level flight, indicates whether it is in proper flight status for landing. The LSO can learn to observe the relationship of the aircraft's structures and its silhouette, becoming proficient in the recognition of approach attitudes. In approaching at the proper attitude the aircraft would be given a "cut" and would then be able to drop to the deck quickly in the right pitch attitude for engagement of the hook, without tending to drift forward. It should be noted that the LSO also has information from the engine sounds which provide an important clue to power setting, another significant element in a proper approach.

We can now understand what the LSO does in daylight to determine whether the aircraft is in the proper angle-of-attack for landing. He inspects the aircraft's attitude, relates it to any change in altitude which the airplane is undergoing, ties this information in with his recognition of power setting from engine sounds, evaluates these data in light of his experience with the exact aircraft model, and draws his conclusion as to what signal motions are in order.

During the day, the success of these techniques is highly dependent upon direct visual examination of the approaching aircraft. Barring adverse weather conditions, the LSO and his assistants who relay information on deck and aircraft conditions, perform their functions with a very high level of efficiency and success. A good pilot can be trained to undertake LSO duties in daylight with only a reasonable amount of instruction.

But when the conversion to night duties is contemplated, an LSO needs a much higher level of skill and a much longer period of training. This is apparent from a realization that there is a great reduction in the number of visual cues available to him. It would seem that any aid that can be given for the performance of LSO duties would not only make the task easier and more efficient, but would also shorten the length of time required to train the day LSO to assume the duties of a night LSO. This time saving would be quite significant in a period of national emergency.

Largely, an LSO is dependent upon the interpretation of an aircraft's exterior lights for night approach control. With clear weather providing a good horizon, or in moonlight when the aircraft might be silhouetted or illuminated, additional visual guidance may be obtained. In any case, we cannot escape the fact that the three basic approach elements, condition, position, and attitude must be determined from visual cues.

Because numerous reports have been received that the presently used night approach LSO aids leave considerable room for improvement, the Bureau of Aeronautics gave our laboratory the problem of investigating possible new techniques.

At present, carrier based naval aircraft are equipped with the usual exterior lights plus an approach light. For position determination, the LSO used the aircraft's running lights. In at least one case, the position lights as designed were not visible to the LSO during the latter phases of the approach. This condition has been remedied by relocating the running lights to a new position more forward on the wing-tip.

The approach light, located in the port-wing or nose of the aircraft, supplies several forms of information. If the wheels and hook are not in the locked-down position the

approach light will not be on. However, the major function of the light is to convey attitude information, which, it will be remembered, indicates angle-of-attack when the aircraft is in level flight. The fixture construction consists of a single #307 lamp and a color filter 2 1/4" in front of it. The filter consists of an upper, wide red region; a central, narrow yellow region; and a lower, wide green region. When viewed at some distance from the fixture, a red, yellow or green light will be seen depending upon whether the observer is above, on or below the axis of the light. These cut-offs are not sharp, however. When properly calibrated, it can be recognized that the light color seen will be indicative of the plane's pitch-angle with relation to the observer. As applied to his perceptual problem, the LSO can roughly judge the aircraft's attitude from the observed color if he takes into full account the aircraft's position with respect to altitude and distance. This is a difficult task accomplished only by experienced LSO's. The pitch and roll of the carrier deck and the rapid changes in the aircraft's position result in sharp changes in the angle of view of the LSO, so that different colors are seen in rapid succession offering no clear and consistent indication of the attitude of the aircraft.

In approaching the development of improved visual aids for the night observational task of the LSO, it was considered that two general avenues might be explored:

(a) Is there any way in which a view of the aircraft itself can be obtained comparable to the perception in daylight?

(b) In what way can signal lights convey information better than present methods?

The first general possibility leads to the consideration of floodlighting the aircraft. Leaving aside the question of security from enemy detection, we can consider aircraft and carrier mounted visible, ultra-violet and infra-red flood lighting sources. It is basically impossible to allow visible light to reach the pilot's eyes since this would cause glare, loss of dark adaptation, and interference with his view of the carrier and the LSO. Therefore, visible flood lighting cannot be used.

Some experimentation has been conducted with ultra-violet sources on the aircraft to activate fluorescent painted exterior structural areas. Reports of test flights are that this equipment improves visibility of the aircraft. However, the difficult maintenance problems, the added weight, the power requirements, and the airstream interference constitute pertinent disadvantages. Infra-red techniques with aircraft mounted sources would be equally troublesome.

The possibility of using infra-red on the carrier deck to track the approaching aircraft seemed to offer the best opportunity for accomplishing two objectives:

(a) elimination of all special equipment from the aircraft; and

(b) the nearest approach to day-time visual conditions giving the LSO a view of the entire aircraft through special electronic receivers.

We have conducted considerable laboratory and field work utilizing high intensity infra-red sources, high infra-red reflective paint, and the best available image-forming receivers. A number of factors were found to be serious deterrents to the successful utilization of these methods. These are:

(a) Insufficient clarity and range of the best available receivers. Extremely fine detail is required to detect the items of interest.

(b) The difficulty of maintaining adequate tracking of the aircraft.

(c) Atmospheric interference even in relatively light haze.

(d) Psychological difficulties involved in transferring from instrumented visual perceptions to direct view as would be required in the final, critical moments of the approach.

For these reasons this technique is not being further explored at this time.

We, therefore, turn to signal lights as offering the better avenue for immediate amelioration of the LSO's problem. The question arises as to whether methods other than the present slant range device exist for conveying attitude information. Three possibilities are: airspeed controlled lights; horizon-gyro-controlled lights; and angle-of-attack controlled lights. In these systems a red light would mean a nose low attitude or high speed, a green light nose high attitude or slow speed, and a yellow light correct speed or attitude for approach.

Instruments to accomplish all three types of control for the signal lights have been developed and extensive field evaluation trials have been conducted and are continuing. The primary source of opinion data on the effectiveness of the experimental systems are the participating experienced and inexperienced LSO's.

Each of the proposed systems has certain advantages and defects which are to be considered in forming a judgment concerning their value.

(a) Airspeed control: The primary difficulty is that the proper airspeed for the approach is not a fixed quantity but is dependent upon loading. Therefore, a pre-set calibration cannot be used with the instrument. The pilot has to make a calculation of what the approach speed should be for his current loading. He then sets a cockpit control to make this speed the "yellow speed" on the indicating system. Inherent in this technique is not only the possibility for error on the part of the pilot in setting the cockpit control, but also, because of this same factor, the likelihood of lack of confidence on the part of the LSO in the indication. Another point of criticism is the fact that the day LSO methodology, involving attitude estimation, is not duplicated in this indicating system.

(b) Gyro-horizon control: By utilization of the pitch signal from an electrical auto pilot gyro to control the signal lights, absolute attitude information can be indicated. The improvement over the present attitude indicating light lies in the fact that this indicator is independent of the relative positions of the observing LSO and the aircraft. Altitude and distance estimations are not needed to interpret the meaning of the indication. However, level flight, which is in practice of the correct approach path, must be presumed if the observed attitude is to be significant in indicating proper orientation for approach. In the equipment designed by LCDR A.J. McEwen of NAESU, controls are available to make the proper approach attitude angle the center of the "yellow" zone, to adjust the width of the "yellow" zone, to determine the width of the "green" and "red" zones, and, finally, to provide slow flashing for the extreme "green" and "red" zones. Added features are optional use of cockpit indications duplicating those seen by the LSO and the feeding into the system of a low altitude warning from the radio altimeter to produce a fast flash in the signal. A "gear not locked down" indication is made by breaking the circuit to the lamps.

(c) Angle-of-attack control: The angle-of-attack can be determined directly by a pick-up device located in the free air stream outside the aircraft in a position free from turbulence. Jet aircraft are particularly suitable for this type of instrumentation. However, it is yet to be determined whether such an instrument will be suitable for approach

light control. One major advantage of this system is that a direct angle-of-attack indication to be used by the LSO, does not need to be tempered by additional estimations of level flight, distance or altitude of the aircraft.

After extensive tests in field carrier landings and in tests during carrier operations using reciprocating engine type aircraft, the participating LSO's have shown considerable preference for the gyro-horizon controlled indicating system over the present and air speed controlled systems. In general, the explanation is that the attitude indications are independent of the LSO's position and, therefore, the LSO has greater accuracy and confidence in his performance.

Each of the three signal light colors used has its own fixture and lamp, and thus a much higher level of brightness and a better distinctiveness of color are obtained than with the older approach light. The LSO's have made much favorable comment on this aspect. As for the placement of the lights, they have been experimentally removed to the lower surface of the flaps. This provides additional "flaps down" information and even allows for landing gear inspection because of the flood lighting effect when the lights are in this location.

As with all equipment, complication leads to concern about greater maintenance difficulty and decreased reliability. The gyro controlled system, threfore, requires extensive operational testing. It is also to be discovered whether LSO's will tend to show too great a dependence upon the light indications to the exclusion of other informational cues. It would not be amiss to emphasize again that LSO functioning is a complex of a many forms of perception, interpretation, and translation and that no hasty simplification would be in order.

Progress Report of the Working Group on Illumination and Dark Adaptation

William S. Verplanck
Harvard University

The working group on illumination and dark adaptation was constituted in mid-February for the purpose of reviewing the literature and preparing a technical summary of the knowledge concerning the relation between illumination and dark adaptation. The working group consists of the speaker as Chairman and Mr. Mitchell of Harvard University as working member. Mr. Mitchell is a student of Dr. Crozier's and of the Psychology Department of Harvard University and is studying sensory psychology and sensory physiology.

The working group has begun by searching standard bibliographical sources. In general there are three classes of reports available: (a) careful measurements made under the optimum laboratory conditions; (b) Laboratory measurements utilizing less preferred instruments and methods; (c) field studies attempting to relate some practical kind of activity to the illumination prior to dark adaptation. The working group expects to emphasize the first class of results, and to summarize the second two classes, with the idea that they will serve to validate or aid in the interpretation of the more precise laboratory results.

Approximately 200 pertinent references have been discovered to date. The sources which have been searched to date include the National Research Council Bibliography of Visual Literature 1939-1944 and Supplement, and the Psychological Abstracts. Additional references which will be searched include the NMRI duplication of the Luckiesh bibliography, Biological Abstracts, the annual reviews of psychology and physiology, and standard reference sources on visual research.

It is anticipated that by the end of the summer the literature will have been searched and evaluated, and it will be possible to summarize the extensive research conducted in connection with this problem in such a fashion that unnecessary research in this area need not be carried out.

A Report of the Executive Countil

Colonel Victor A. Byrnes, Chairman

The Executive Council reviewed the status of various projects which have been recently organized under working groups. The Executive Council is pleased to report that the Armed Forces Visual Screening Examination is now completed. This project has been active for a number of years, and it is a pleasure to see it completed. A more detailed report of the working group was presented by Dr. Wolpaw at the Friday meeting.

The working group on reflection optics, under Dr. Theodore Dunham, Jr., has completed its final report of the potential use of reflection optics in visual telescopes. The report of this working group consists of a summary of various activities of the working group and a bibliography of literature pertinent to reflection optics. The Executive Council wishes to express its appreciation to members of the working group for a good job.

A working group on visibility at high altitudes headed by Dr. Blackwell has been reviewing the literature and is expected to submit a report in the near future indicating the gaps in knowledge which are evident. Once these gaps are known, efforts will be made to provide the necessary information.

A working group on night vision training has been appointed to review the research activities in night vision training of the School of Aviation Medicine at Randolph Field. The Air Force is interested in conducting a program of night vision training and desires to utilize the best possible equipment for this project. In order to save time in evaluating various possible devices for night vision training, a working group has been appointed consisting of individuals who have had considerable experience in this field, and who are, therefore, able to evaluate the devices in a preliminary fashion before elaborate development and research activities are carried out. This working group is headed by Dr. William S. Verplanck and plans to visit Randolph Field within the next week.

The activities of the working group on illumination and dark adaptation have been summarized by Dr. William S. Verplanck, chairman of the working group.

Arrangements are being made to establish a working group on aircraft cockpit and instrument lighting under the chairmanship of Dr. H. K. Hartline. This working group was set up at the request of the Aero Medical Laboratory at Wright Field. The purpose of the working group is to recommend research and development in order to provide an adequate cockpit and instrument lighting installation for Air Force aircraft.

A working group is being constituted under the chairmanship of Dr. Glenn A. Fry to study the problem of radar equipment utilized on long-range bombing missions. There is a great deal of information in the hands of various scientists which can be utilized to minimize the visual fatique encountered by radar operators on the forty-hour bombing missions.

The Executive Council also wishes to report that Dr. Richard Trumbull has prepared a review of the evidence pertinent to the use of the Verhoeff test of stereoscopic vision in the military services.

The Executive Council wishes to announce that the terms of office of two members of the Council, Dr. Conrad Berens and Dr. E. O. Hulburt, will expire on July 1. The Executive Council has prepared a slate of nominees, and members of the Committee will be polled by mail to fill the two vacancies from the Executive Council.

DISCUSSION:

Dr. Uhlaner asked if it would be in order to request that the report made in connection with night vision training would be sufficiently detailed so that even though the recommendations are based on the experience of members of the group, the basis for the recommendations will be indicated sufficiently clearly so that others will have the opportunity to profit by the report.

Colonel Byrnes referred the question to Dr. W. S. Verplanck, chairman of the group.

Dr. Verplanck stated that the recommendations made by the working group would be documented whenever possible. Dr. Verplanck commented that the report will also contain hunches of members of the group, since it is the desire of the School of Aviation Medicine to have "educated guesses" as well as all the available facts.

ABSTRACTS

296. Visibility of Navy Radioactive Self-Luminous Personnel and Deck Markers.
Boardmann, L. J. and L. H. Dawson
U.S. Navy, Naval Research Laboratory, Washington, D.C.
NRL Report 3591, 24pp. December 28, 1949 (0)

"The evaluation of the New London Navy Lantern test was conducted in terms of the American Optical Company's Psuedo-Isochromatic Plates, 1940 edition, as the independent criterion. 372 consecutive patients (civilians, officers, and enlisted personnel) of the Department of Ophthalmology, School of Aviation Medicine, Pensacola, Florida served as the experimental population. Of the 372 subjects, 41 (11.02%) were judged as color deficients by the A.O. plates and 148 (39.78%) were judged as color deficients by the N.L. test.

"For each subject the A.O. plates were administered in an illuminated room. Of the 372 subjects, N.L. tests and retests were administered to 303 in an illuminated room; the remaining 69 subjects were tested in a dark room.

"On the basis of the analysis of results for each of the foregoing conditions it was concluded that: (1) to enjoy the maximum test-retest reliability, the N.L. test must be employed under the conditions for which it was designed; (2) under these conditions the N.L. test's selectivity is poor when judged by strict statistical standards; (3) the most favorable passing criterion for the N.L. test appears to be one of three errors inclusive; and (4) with the alteration of the passing criterion it becomes apparent that the circumstances will allow for a substantial improvement of the N.L. test. On the basis of the improvement possible, it may be concluded that the additional experimentation necessary to achieve this gain would be justified.

"Several possibilities for improvement of the N.L. test are also considered."

297. Evaluation of the New London Navy Lantern Color Vision Test.
Rand, G. W. and James T. Ray
U.S. Naval School of Aviation Medicine, Naval Air Station
Pensacola, Florida, and Tulane University, Joint Memorandum
Report No. 1. 17 pp. May 16, 1950 (0)

"The time necessary for an observer to see clearly, under simulated darkened ship conditions, radioactive self-luminous personnel and deck markers has been measured. Most of the observations were made on the Standard Navy radioactive green and red markers, the types most generally used. A brief discussion is given of the physiological action of the human eye. Curves are included on the visibility of markers of known luminosity against backgrounds of known brightness and with the eye adapted to selected levels of illumination. Tentative recommendations are given for use of the markers."

298. Perception of the Vertical: X · Adaptation Effects in the Adjustment of the Visual Vertical
Passey, George E. and James T. Ray
U.S. Naval School of Aviation Medicine, and Naval Air Station Pensacola, Florida, and The Tulane University, Contract N7onr-434
T.O. I. Joint Project Report No. 17 10pp. October 20, 1950 (0)

"The object of the present study was to examine the effects of postural adaptation to tilt and a combination of this with adaptation to a tilted visual target upon the adjustment of the visual vertical. Eight Ss were divided into two experimental groups of four each. All Ss were required to adjust a visual target to the vertical from a position of 45° tilt in each upper lateral quandrant. During the adjustment they were maintained at positions of 0°, 5°, 10°, 15° and 20° in each upper lateral quadrant. Each possible combination of S tilt and target tilt was employed and presented in random order to preclude any effects upon adjustment. Experimental Group I was maintained in a tilted position for a period of 30 seconds prior to adjustment of the target. Subjects in Group I were denied visual access to the tilted visual target during this time in order that they be exposed only to postural adaptation. Experimental Group II was subjected to postural adaptation as was Group I. Subjects in Group II were in addition required to observe the tilted visual target in an attempt to produce adaptation to tilted visual targets. Results indicate no change in variability of the indices of average and constant error with any of the experimental conditions employed. With increase in the amount of body tilt maintained during adjustment of the visual vertical, there is an increase in average error of adjustment and a shift of constant error of adjustment in the direction of either the Aubert or the Müller phenomenon. When adjustments under the conditions of adaptation were compared with immediate readjustments there was found to be no effect upon adjustment of the visual vertical as reflected in the indices of average and constant error."

299. Studies in the Accuracy of Movement. III. The Bisection and Duplication of Angular Extents as a Function of Size of Angle and of Type of Endpoint Cue
Spragg, S.D.S. and D.B. Devoe
Technical Report SDC 241-6-4, Department of Psychology, University of Rochester, Contract N6on4-241, T.O. 6, Project Designation NR-783-006, 26pp. October, 1950. (0)

"This report is the third in a series of studies on the accuracy of movement. Experiments are reported in which subjects (N = 12) turned a 2.5 inch diameter knob through an angular extent and then attempted either to bisect that extent or to duplicate it. The present study is concerned with the accuracy and precision of such responses as a function of the angular extent to be bisected or duplicated (ranging from 20° to 160°) and of the type of end-point cue provided (tactual-kinesthetic, visual, or auditory).

"The results presented as mean average error (AE) and mean constant error (CE) showed no significant differences related to type of end-point cue. Size of angle was found to be a highly significant variable. Accuracy and precision increased significantly with increase in angle size, both for duplication and for bisection, with most of the improvement being achieved from 20° to 80° and relatively little from 80° to 160°. For bisection a rather large positive CE (over-setting) of 25 per cent was found at 20° which remained positive throughout but was reduced to 11 per cent at 160°. For duplication a positive CE of 14 per cent was found at 20° but was reduced rapidly and was of zero order for 80° and 160°.

"These results indicate that in the design of equipment controls in which a control knob is set by duplicating or by bisecting a sampled angular extent of movement (e.g., as in the

'dead' zone in focussing or tuning), the control knob should be geared in with the rest of the instrument so that the perceived 'dead' zone or region of uncertainty will be at least 80°. Proportional accuracy as well as consistency of performance should be greatest under such conditions."

300. Studies in Complex Coordination. II. Performance of the Two-Hand Coordinator as a Function of the Relations Between Direction of Rotation of Controls and Direction of Movement of Display
Norris, E. B. and Spragg, S. D. S.
Technical Report SDC 241-6-5, University of Rochester, Department of Psychology, Contract N6on4-241, T. O. 6, Project Designation NR-783-006 17pp. November, 1950.

"The present study was designed to investigate performance of a two-hand coordination task as a function of the direction of rotation of the controls in relation to the direction of movement of the display. The SAM Two-Hand Coordinator was modified so that (a) the effect of the direction of rotation of the crank of the movement of the display could be reversed and (b) the cranks could be placed in either the vertical or horizontal plane.

"Two groups of 48 subjects each were given four trials, one on each of the combinations of directions of rotation described below. In terms of the movement of the target follower, to the left or right means left or right in a plane parallel to the frontal body plane of the subject, while front and rear mean to the front or rear of apparatus in a plane perpendicular to the frontal body plane of the subject.

Condition	Clockwise movement of the:	Moves the target-follower to the:
A	Left crank	Left
	Right crank	Front
B	Left crank	Right
	Right crank	Rear
C	Left crank	Right
	Right crank	Front
D	Left crank	Left
	Right crank	Rear

"The only difference between the two groups of subjects was the plane of rotation of the cranks. For Group I the two cranks were placed in a vertical plane parallel to the frontal body plane, and for Group II the left crank was placed as in Group I, while the right crank was placed in a vertical plane perpendicular to the frontal body plane.

"The results were analyzed in terms of the mean time on target for each of the combinations of direction of rotation. Experimental condition B (see above) was found to be superior to A, C, and D for both Group I and II. In neither Group I nor II were any of the differences between conditions A, C, and D statistically significant. Group II was superior to Group I in terms of the overall estimate and in terms of each of the experimental conditions.

"These results indicate that in the design of equipment controls where control cranks must be turned simultaneously by the two hands, superior performance will result if there is

continuity between the plane and direction of movement of the controls, and the plane and direction of movement of the display."

301. The Brightness and Polarization of the Daylight Sky at Altitudes of 18,000 to 38,000 Feet Above Sea Level
Packer, D. M. and C. Lock
Naval Research Laboratory, Washington, D. C., NRL Report 3713, 59pp.
July 31, 1950 (0)

"The brightness and polarization of the daylight sky over Arizona and southern California were measured from B-29 aircraft while flying at altitudes of 18,000, 27,500, 34,000, and 38,000 feet above sea level. Comparison of the results with the Tousey-Hulburt theory of sky brightness showed that the theory agreed fairly well with the experimental data for all altitudes of observation, for all points in the sky more than 30° from the horizon and for scattering angles greater than about 40° from the sun, when an atmospheric attenuation coefficient of 0.017/km was assumed. The values of sky brightness observed at scattering angles within 30° of the sun indicated that large scattering particles were present in the atmosphere overhead at all altitudes of observation, including 38,000 feet. The measured values of sky brightness and polarization are presented graphically, plotted as functions of the angle between the sun and the observed point in the sky."

302. Field Tests of Optical Instruments: Further Results
W. S. Verplanck
Department of Psychology, Indiana University, Contract N6ori-180, T. O. III. NR 143-292. 30 June 1950 92pp. (R)

This report contains the final results of the analysis of data gathered in the field tests of optical equipment performed at the U. S. Submarine Base, New London, Conn. in late 1945. The following are among the conclusions reached:

(1) The Tiffany Foundation data predict visual performance in the field. The sighting ranges predicted by the Tiffany Visibility Forecasting Nomographs may be accepted with confidence as conservative estimates of sighting range, the actual ranges being as much as 10-25 percent greater than those predicted.

(2) No evidence was found which would suggest that the relative performance of binoculars described in report NavOrd 77-46 is altered by visibility changes.

(3) It was found that the performance of a particular type of binocular cannot be entirely predicted by its optical properties as an earlier report had suggested.

(4) The visual performance of sighting is not a reliable one, but one which varies from day to day in an as yet unpredictable fashion, possibly as a function of complex non-visual variables.

303. The Slope Line Approach Light System
H. J. Cory Pearson
Civil Aeronautics Administration Technical Development and Evaluation Center, Indianapolis, Indiana. Technical Development Report No. 104 37pp. March 1950. (0)

"This report describes a three-dimensional pattern of lights developed as an approach light system for landing aircraft under conditions of restricted visibility. In this design the lights are linear in form, and are mounted in two geometric planes which intersect at right angles along the line of the approach path. This system of approach lights provides a pilot with a unique and distinctive pattern which can be identified readily as an approach light system and which indicates visually his attitude and position relative to the proper approach path.

"With the aid of these indications a pilot is enabled to make a visual contact landing under visibility conditions materially more restricted than has hitherto been possible.

"The slope line approach light system has been adopted as standard for the United States by the Air Force-Navy-Civil Subcommittee for Visual Aids to Air Navigation, and confirmed by the Aircraft Committee of the Munitions Board."

304. The Discrimination of Color: I. An Experimental Evaluation of Four Methods for Measuring the Difference Limen of Chromaticity.
Sperling, Harry G. and Dean Farnsworth
Medical Research Laboratory, U.S. Naval Submarine Base, New London, Conn. Vol. 9. pp. 54-89 September 1950. (0)

"The difference limen in one dimension through a single point in the I.C.I. chromaticity plane was measured using four different psychophysical methods and four surround brightnesses with four highly trained, color normal observers. The psychophysical methods were: (a) Method of Constants - judged 'same or different,' (b) Method of Constants - judged 'with direction,' (c) Method of Paired Comparisons and (d) Method of Adjustments. The data were evaluated using a Latin square design and the analysis of variance.

"The results showed: (a) differences in the magnitude of the D.L. over all methods were significant at the 1% level; the smallest D.L.s were obtained with Method of adjustments and Constants 'with direction,' (b) inter-observer differences were significant at the 1% level, (c) there was no significant variation in the magnitude of the D.L. with variation of surround brightness, (d) no significant residual interactions were found, (e) comparisons of test-retest variability were made between the total within-subclass variance of each pair of methods resulting in the following order of increasing variability: Adjustments, Constants 'with direction,' Constants 'same or different,' Paired Comparisons.

"A theoretical relation was derived relating the Constants D.L. to the Adjustments measure."

305. The Effect of Ultraviolet Radiation From Flourescent Lights on Dark Adaptation and Visual Acuity
Sexton, Mary
Malone, Florence
Farnsworth, Dean
U. S. Naval Submarine Base, New London, Conn. Medical Research Laboratory. Report No. 169. BuMed Project NM 003 041.38.01 Vol. 9 pp. 301-317 December 1950 (0)

"The ultraviolet radiation from flourescent light of the highest brightness level commonly used in submarines was experimentally measured to determine its effect upon absolute scotopic threshold and its effect upon visual acuity.

"To study the effect upon absolute scotopic threshold, two observers pre-adapted for one hour to each of the following illuminants at brightnesses of 20 footlamberts: flourescent light, ultraviolet-shielded flourescent light, and incandescent light. After each pre-adaptation, the observer's course of dark adaptation was measured over a four-hour period; thresholds were taken every half-hour. No apparent or significant differences due to these types of illumination were found between these preadapting conditions.

"To study the effect upon visual acuity, the two observers pre-adapted to each of the three illuminants and, after each pre-adaptation, continued under the same illuminant with a visual performance task -- the Weston Cancellation Test of rings with gaps of .84, 1.26, and 1.68 minutes of arc. The over-all results of tests under these three illuminants indicated that there were no significant differences between mean acuity scores as determined by 't' tests.

"It was found that ultraviolet radiation is not produced in sufficient amounts by submarine flourescent lights, held at or below the reflected brightnesses used, to yield measurable effects upon the types of visual tasks here employed. These tasks were of a moderate degree of difficulty and similar in visual requirements to the visual tasks performed aboard submarines. Therefore we conclude that the ultraviolet content in submarine flourescent lights has very small, if any, effect upon visual performance when the installations are in accordance with recommended lighting practice."

306. A Study of the Relation Between Photopic and Scotopic Visual Acuity
J. E. Uhlaner and Irving A. Woods
Personnel Research Section, AGO. PRS Report 858 U.S. Army 22 pp. June, 1950 (0)

"Early in World War II it was realized that the U.S. Army had a problem in evaluation of the ability of soldiers to see at night. The need for training in night-seeing techniques carried with it the problem of proper personnel selection devices, which in turn led to the development of the Army night vision tester. However, the relationship between day visual acuity and night visual acuity had not been determined. If a high degree of relationship between the two abilities exists, there is no need to measure them separately; on the other hand, if there is little or no relationship, separate measures of the two are needed. The present study sought to determine the relationship between day (photopic) visual acuity and night (scotopic) visual acuity by testing 200 soldiers with a battery of day vision tests and a night vision test. These men were studied under standardized and carefully controlled conditions. The results of this study showed that there was a positive relationship between the measures of day and night visual acuity for this group. This relationship was not high

enough to substitute a man's score on one ability for his score on the other. This finding suggests that if personnel selection procedures must provide certain instruments appropriate to measuring both types of vision, for the present at least, one measure of each type would be necessary. However, there is an indication that further study may determine levels of day vision which will give reasonable assurance of above-average night vision ability for a wide-range population."

307. Speed and Load Stress in a Sensori-Motor Skill
R. Conrad
Medical Research Council, A.P.Y. 134/50, Applied Psychology Research Unit, The Psychological Laboratory, Downing Place, Cambridge. 11pp. 1950. (0)

"In this paper, previous work on the distribution and division of attention is critically reviewed from the point of view of its relevance to the study of skill. It is felt that fundamental methodological weaknesses minimise its value to this field of research. In particular, the presence of time as an environmental factor in skilled behaviors has been consistently underrated.

"Time is effective in skill in the form of speed. This in the simplest terms can be described as the rate at which critical display changes occur. Speed, however, needs to be qualified by another factor - load - which describes the number of independent streams of signals which comprise the changing display.

"An experiment was carried out to study the effects on skilled performance of increases of speed and load beyond the point at which deterioration occurs. Twenty subjects did the same task, which demanded adaptation to a continuously changing situation, under three different conditions of load, and at five different speeds for each load.

"The results can be summarised as follows:

(a) The number of signals not responded to at all bears a logarithmic relationship to the rate at which they are presented.

(b) At any one speed, the incidence of this type of error depends markedly on the load content of the display.

(c) Statistical interaction between speed and load effects is demonstrated.

(d) Of the responses made, the size of errors of timing is not affected by the speed of the task. But doubling the load approximately doubles the timing error."

308. The Twenty Dials Test Under Quiet Conditions
D. E. Broadbent
Medical Research Council, Applied Psychology Research Unit, The Psychological Laboratory, Cambridge. 12pp. August, 1950 (0)

"As an initial step in the investigation of the effects of noise, an apparatus has been developed which is intended to test the vigilance of subjects for visual signals appearing from a large number of possible directions and remaining visible until dealt with. This apparatus is analogous to a set of twenty steam pressure gauges, a signal being a movement of the pointer on a gauge to lie above a danger level on the dial. It was desirable to

determine the characteristics of watch-keeping on this apparatus under quiet conditions before proceeding to the actual noise trials. Forty subjects have therefore been given two runs each on the apparatus, one run consisting of 1 1/2 hours, or 15 signals.

"The results indicate:

(a) Approximately a quarter of the signals are observed at the time of occurrence; if the subject happens to be looking in the right direction the motion of the pointer will attract his attention.

(b) Of the remainder of the signals, which require a rapid examination of each dial in turn, nearly half are noticed in twelve seconds or less.

(c) The incidence of these comparatively rapidly noticed signals shows no consistent trend within runs, but it does show an improvement between runs, presumably due to practice.

"A study of individual differences shows:

(d) Some individuals improve more markedly than others from Run 1 to Run 2.

(e) These same individuals deteriorate more during runs, both in the frequency with which signals are noticed by seeing the pointer actually move, and in the proportion of the remaining signals observed within twelve seconds. A subject who is less alert towards the end of runs is also relatively less alert after a long blank interval without any signals.

"Examination of the effect of dial position upon the speed of signal detection shows:

(f) When only a minute or two has elapsed since the last signal, the centre of the display is more closely observed than the ends.

(g) When more than five minutes have elapsed since the last signal, this preference is reversed and the ends of the display are more closely observed than the middle.

(h) Those who show the most marked changes in their direction of visual regard with increasing length of time since the last signal, also show the most marked changes of the same sort with increasing length of time since the beginning of the watch.

"In view of the regularity of these differences between people as regards their performance trends within the watch-keeping spell, it seems reasonable to suppose that chance factors are not entering into scores on this task to any appreciable extent; consequently the apparatus is now ready to be tried under noise conditions."

309. Studies in Space Perception
Cecil W. Mann
U. S. Naval School of Aviation Medicine, Naval Air Station, Pensacola, Florida. Joint Project Report No. 18. Tulane University under Contract N7onr-434 T. O. I. 18pp. October 1950. (0)

"The evidence presented supports the hypothesis that space orientation is a complex function involving, in the intact organism, all sense modalities that, under the circumstances, are appropriate. Moreover, it involves not only the receptor but the motor aspects of perception. The total effect of body tilting under static conditions or under the influence

of centrifugal force is that the organism not only received the impulses but reacts to them. With a tilted visual field there is a tendency towards postural compensation by appropriate motor responses. The perceptions involved in space orientation, both visual and postural, are motor as well as receptive.

"When it comes to the experimental control of factors, there are certain difficulties apparent. It is not difficult to eliminate visual factors, and when this is done it is found that the individual makes postural judgments with a high degree of accuracy, both from positions of static tilt and under the influence of centrifugal force. The addition of a visual field produces compromise judgments, but the fact that a visual field influences judgment does not warrant the conclusion that it determines judgment. It is also true that in those experiments in which a rod must be set to vertical in the presence of a conflicting visual field there is visual conflict, and with body tilt -- whether due to static tilt or to centrifugal force -- visual and postural conflict. The displacement of judgment produced when a visual field is added cannot be taken as evidence that the somesthetic cues are unimportant. Every flier of experience knows that, under certain circumstances, he faces the temptation to leave his instruments and fly by somesthetic cues; that this is a dangerous matter is admitted readily. It is evidence for the strength, albeit the unreliability, of the somesthetic cues.

"The experimental control of somethetic cues is difficult; their complete elimination is impossible. Thus, under all conditions of visual perception there is the added complex of somesthetic factors. It had already been pointed out that when these somesthetic cues do not enter into the solution of a visual perceptual problem, as in simultaneous visual conflict or in visual conflict uncomplicated by body tilt, the individual will neglect them. When body tilt, with its accompanying somesthetic cues, is added to the problem of visual conflict, compromise judgments of the vertical are made. It should be noted, however, that these compromise judgments are more variable than those made in the absence of the conflicting visual field. The arc of uncertainty is larger; they are made with less confidence than those made with somesthetic cues alone. Obviously the most accurate judgments of the vertical are those made by the use of both visual and somesthetic cues, and if we accept the proposition that in visual perception there are motor as well as sensory components, these results would lead to the conclusion that the accuracy is due to the integration of somethetic and somesthetic-visual cues.

"The determinants of the visual vertical are, according to the theory of Wetheimer and Koffka, the main lines of the visual framework. Thus, if the whole visual field of the observer is tilted, verticality and horizontality are altered correspondingly. This neglects the obvious experimental finding that there is never complete acceptance of the tilted visual field; there is always motor response accompanying the perception which produces the tendency to correct the false visual impression by postural compensation. Moreover, wh the eyes are flexible, they are not completely labile. Their limits of mobility are presu able concomitant with the needs of a fairly symmetrical organism which is, under normal conditions, able to maintain a postural upright without the aid of visual cues.

"Gibson and Mowrer believe that 'visual orientation presupposes postural orientation. Once orientation to gravity is granted, visual cues can make their contribution both to posture and to the uprightness of seen space; they become specific.' They believe that because of the priority of gravitational factors, the visual framework can be automatically corrected during body tilt.

"The labile visual theory proposes that visual perception is a process concerned primarily with sense reception. If the main lines of the visual groundwork are altered, enclosed visual elements are thereby altered. More in line with the experimental results is the theory which regards perception as a discriminatory response involving both sensory and

motor functions; the alteration of the visual framework produces automatically a postural as well as a visual response. Orientation to space, visual and postural, is the outcome of an integrative function which involves not only the receptor organs but motor discriminative responses as well."

310. Age As A Variable in Post Rotational Phenomena
Frederick E. Guedry, Jr.
U. S. Naval School of Aviation Medicine, Naval Air Station, Pensacola, Florida. Joint Project Report No. 19. The Tulane University under Contract N7onr-434 T. O. I. 3pp. November 1950 (0)

"The present experiment indicates that age may be a variable which should be controlled in experiments dealing with vestibular stimulation. The use of t tests to evaluate the data may be questionable on the basis of the large age-range of Group II. This large age-range, however, would only increase variability and hence decrease the 'significance' of differences if age is a factor, or, on the other hand, if age is not a factor such a criticism would not be applicable.

"A more extensive investigation controlling age and the other possible variables mentioned below is contemplated."

311. Distribution Curves of Atmospheric Transmission for Continental United States
United States Coast Guard
Office of Chief, Civil Engineering Division, Washington, D. C.
December 1950 (0)

Graphs are presented in which the frequency of various values of atmospheric transmission is given for twenty-four points in the continental United States. The graphs were constructed from data collected in 1923. The data consisted of accumulated records of whether or not one lighthouse keeper could or could not see other lighthouse lights within his range of geographically possible visibility. Distances to the other lights and their candlepowers were known. The candlepowers were corrected for intermittency by the Blondel-Rey formula and atmospheric transmissions were computed.

312. Visibility Within the Cockpit at High Altitude
In Quarterly Bulletin of the Director-General of Medical Services, Royal Air Force, Air Ministry. P. 9, December 1950 (R)

"It has been said that with an increase in altitude the illumination of a shadow area decreases. This may be true at great heights when the influences of the cloud layers are negligible but it is modified at the altitudes at which aircraft are flying today. An investigation was carried out on the visibility of an instrument panel in shadow and on the brightness of the shadow areas in the cockpit of a Meteor VII at altitudes up to 40,000 feet.

"The results showed that there was a decrease in the visibility of instruments in shadow above 30,000 feet, but that the depth of the shadow areas varied according to their position on the panel and to the cloud or haze conditions prevailing. With an increase in altitude above cloud tops the trend was for all parts of the instrument panel in shadow to become darker. However, at the upper part of the panel this trend was modified or reversed when broken cloud or solid cloud floors happened to be beneath the aircraft. The reason for

this is that at high altitude the scattered light comes mainly from below the aircraft, and those parts of the cockpit and instrument panel which are in direct line with the denser layers of the atmosphere receive most illumination. In contrast, the lower parts of the cockpit and instrument panel in shadow, being in line with the darker sky towards the zenith, receive less light. There is thus a deterioration in the visibility of instrument dials placed in the lower part of the panel. This is aggravated by anything which shades the dials from the scattered light below the aircraft, such as dial faces which are not flush with the panel, a high coaming or cowling about the instrument panel.

"A reduction of these aggravating factors is recommended. Other suggestions which have been made for improvement are a white finish to the back of the cockpit or the use of flood lights, invisible to the pilot, which are directed upwards against the instrument panel."

313. Visors for Aircrew
In Quarterly Bulletin of the Director-General of Medical Services, Royal Air Force, Air Ministry. Pg. 10, December 1950 (R)

"For aircrew use visors in general possess two advantages over Mk VIII goggles. First, they do not restrict binocular vision as is inevitable when goggles are worn. Secondly, they are adaptable. Goggles are either on or off; whereas a visor, which will normally be worn in the HALF-UP position, can be adjusted to cut out the direct light falling on the eye, thereby reducing intra-ocular scatter and causing a real improvement in forward vision. As a protection against wind the visor is considered to be almost as efficient as that obtained by the Mark VIII goggles; in a slip-stream the curved surface of the visor offers less wind-resistance. As a result the head remains steadier, thus ensuring clearer vision. Further wind tunnel tests are being carried out and both Visors Type A and B will shortly be issued for user trials."

314. Graded Density Spectacles
In Quarterly Bulletin of the Director-General of Medical Services, Royal Air Force, Air Ministry. Pg. 12. December 1950 (R)

"Opportunity to examine specimens of anti-glare spectacles having filters in 'rose smoke', 'neutral' and 'contrast' tints has been provided through the courtesy of Messrs. Bausch and Lomb Optical Company, Rochester, New York. All lenses had a metal sputtered film of graded density, some being dense at the top, some at top and bottom with clear centers.

"Preliminary reports on the flight trial of these spectacles showed that the 'neutral' is the most suitable from all points of view and was preferred by most individuals participating in the trial. The 'contrast' spectacle gave no evidence either of improved visibility or of appreciably improved definition. 'Rose smoke' was preferred by some, but not by others. The spectacles which were graded from below upwards as well as from above downwards were found to be unsatisfactory in flight because, although they reduced glare from below, they also reduced the visibility of the instruments, making it difficult to see them without bending the head far forward in order to view them through the central clear part of the spectacle lens. In spectacles with single grading from above downwards this difficulty did not arise, but visibility upwards when flying at high altitude was adversely affected, as a sky already dark towards the zenith was rendered still darker when viewed through the filter.

"Of the three tints examined the neutral filter appeared the most suitable, but it should not be associated with any form of grading when used in spectacles for flying."

315. The Brightness and Polarization of the Daylight Sky at Altitudes of 18,000 to 38,000 feet above Sea Level
Packer, D.M., and C. Lock
Naval Research Laboratory, Washington D.C., NRL Report 3713.
59pp. July 31, 1950 (0)

"The brightness and polarization of the daylight sky over Arizona and southern California were measured from B-29 aircraft while flying at altitudes of 18,000, 27,500, 34,000 and 38,000 feet above sea level. Comparison of the results with the Tousey-Hulburt theory of sky brightness showed that the theory agreed fairly well with the experimental data for all altitudes of observation, for all points in the sky more than 30° from the horizon and for scattering angles greater than about 40° from the sun, when an atmospheric attenuation coefficient of 0.017/km was assumed. The values of sky brightness observed at scattering angles within 30° of the sun indicated that large scattering particles were present in the atmosphere overhead at all altitudes of observation, including 38,000 feet. The measured values of sky brightness and polarization are presented graphically, plotted as functions of the angle between the sun and the observed point in the sky."

316. The Relation of Dark Adaptation to Duration of Prior Red Adaptation
Mitchell, Richard T., Morris, Ailene and Forrest L. Dimmick
Medical Research Laboratory, U.S. Naval Submarine Base, New London, Connecticut. Report No. 166. BuMed Project NM 003 041.49.01 Vol. 9 pp. 258-277 December 6, 1950 (0)

"The effects of duration of red preadaptation upon the immediate brightness threshold and upon the course of dark adaptation are presented. Measurements were made following seven adaptation periods of 0 to 40 minutes wearing red goggles under a preadapting brightness of 150 mL.

"It was found that red adaptation increased the rate of subsequent dark adaptation so that the 5 log $\mu\mu$L threshold was reached in one half the time after wearing red goggles for five minutes, and in one fourth the time after 20 minutes in red. Forty minutes in red gave no further decrease in dark adaptation time.

"In terms of the total time (red plus dark) required to dark adapt to a threshold of 5 log $\mu\mu$L, the first five minutes of red adaptation showed the greatest efficiency. Five minutes in red goggles followed by 3.8 minutes in darkness are equivalent to 8.2 minutes in darkness. Red preadaptation for long periods (20 minutes or more) produces relatively little dark adaptation compared with the same time spent in total darkness. The sensitivity reached by wearing red goggles for 40 minutes was still 2.75 log $\mu\mu$L above the 30 minute threshold in total darkness."

317. Periscope Acuity at Night. Central and Paracentral Acuity as a Function of Contrast and Adaptation.
Sperling, Harry G. and LCDR Dean Farnsworth
Medical Research Laboratory, U.S. Naval Submarine Base, New London, Conn. Report No. 157. BuMed Project NM 003 041.39.01. Vol. 9 pp. 128-149 November 28, 1950 (0)

"Discrimination of a target approximating the visual subtense of a ship at 5,000 yards on low power was measured with the right eye at nine retinal positions, from central fixation

to 15° off central vision. Target to background contrast was varied to sample a range of visibility conditions at sea. It was found that for all target contrasts at light levels at or below twilight (.27 millilamberts) off-center acuity was greater than central acuity. Acuity at 6° from central fixation was found best but little decline was discovered out to 15°.

"The subsequent effect upon discrimination of the targets of viewing three common visual indicators was measured. After viewing the S. S. radar P. P. I. a long recovery time was required to detect targets illuminated even as high as full moonlight. The 'Christmas Tree' and red illuminated dials produced smaller but appreciable decrement.

"These laboratory tests indicate that viewing radar indicator lights and dials at normal operating brightness is detrimental to periscope vision at night."

318. Variations in Reflex Blink Rate During Visual-Motor Tasks
G. C. Drew
Department of Psychology, University of Bristol, Flying Personnel Research Committee. 13pp. December 1950 (0)

"It has been suggested by Lawson that people with a high reflex blink rate would be handicapped in performing a visual motor-task, and that such people might well be a serious cause of traffic accidents. As the previous literature on this subject could not supply an answer, it was decided to test the hypothesis experimentally.

"The experiment was carried out in two parts. The main part was done in the laboratory, while a validating experiment was carried out on the road. In the laboratory, subjects were required to steer a pencil along a moving track which varied in difficulty. The difficulty of the response was varied by using a direct control on some trials and a velocity control on others. Blink rate, errors, and control measurements were recorded throughout. In the road experiment, cine films were taken of the driver's eyes while driving in heavy traffic and in open country.

"The results of both experiments show:

(a) That there are marked individual differences in blink rate, the relative order of which is maintained in spite of variations in the actual blink rate;

(b) That there is no relationship between the accuracy with which a particular individidual carries out a task of this sort and his blink rate. The rapid 'blinker' is no more and no less likely to be accurate than the infrequent 'blinker';

(c) That the actual blink rate for all individuals varies inversely with the difficulty of the task and the amount of control movement necessary. The blink rate decreases as the necessity for detailed visual control of movement increases. Blink rates when driving a car in heavy traffic, or when steering along an oscillating track, are considerably lower than when driving in open country or when following a straight track;

(d) That the adjustment of the blink rate to the difficulty of the task is achieved not only by an alteration in overall blink rate, but also by a change in the distribution of blinking. The blink rate is approximately constant under constant conditions, but when the task is varying in difficulty, blinking occurs just before and just after periods of maximum difficulty, but is completely inhibited during the periods of maximum difficulty itself."

to 15° off central vision. Target to background contrast was varied to provide a range of visibility conditions at each. It was found that for all target sizes and at light levels at or below twilight (.37 millilamberts) off-center acuity was greater than central acuity. Acuity at 5° from central fixation was found best but little decline was discovered out to 15°.

"The subsequent effect upon discrimination of the targets of viewing three common visual indicators was investigated. After viewing the B.R. ... a longer time was required to detect targets illuminated even as high as full moonlight. The ... 'Tray' and red illuminated dials produced smaller but appreciable decrements.

"These laboratory tests indicate that viewing brightly illuminated ... operating vessels is detrimental to nocturnal vision at sea."

178. Variations in Rated Blink Rate During Visual-Motor Tasks

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"It has been suggested by Lawson that people with a high rating blink rate should be more careful in performing a visual motor task, and that such people might well be a serious cause of traffic accidents. As the previous discussion of this subject could not supply an answer, it was decided to test the hypothesis experimentally.

"The experiment was carried out in two parts. The main part was done in the laboratory, while a validating experiment was carried out on the road. In the laboratory, subjects were required to steer a pencil along a moving track which varied in difficulty. The difficulty of the task was varied by using a drum on which tracks of various widths were shown to the subject on screen: wide, narrow, and ... In the road experiment, cine films were taken of the driver's eyes while driving in heavy traffic and in open country.

"The results of both experiments show:

(a) That there are marked individual differences in blink rate, and each individual has a range which is maintained in spite of variations in the actual task rate.

(b) That there is no relationship between the individual's blink rate, or ... and ... ordinary ... or a ... than the ... subjects.

(c) That the actual blink rate for all individuals varied according to the difficulty of the task and the amount of control movement necessary. The blink rate decreases as the necessity for detailed visual control of movement increases. Blink rates when driving a car in heavy traffic, or when steering along an oscillating track, are considerably lower than when driving in open country or when following a straight track.

(d) That the adjustment of the blink rate to the difficulty of the task is achieved not only by an alteration in overall rate ... but also by a change in the distribution of blinking. The blink rate is approximately ... under constant conditions, but when the task is varied in difficulty, blinking occurs just before and just after periods of maximum demand and is inhibited during periods of maximum difficulty."